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ABSTRACT

The hearing reported in this document examines the gap between what is known regarding how people learn and the teaching methods and materials educators use to teach. The information is gathered from the recent reports of the National Academy of Sciences. The hearing includes the opening statements of Representative Nick Smith, Chairman, Subcommittee on Research, U.S. House of Representatives and Honorable Eddie Bernice Johnson, Ranking Minority Member, Subcommittee on Research, U.S. House of Representatives. Witnesses include Dr. Diane F. Halpern, Professor of Psychology, California State University, San Bernardino; Dr. Jose P. Mestre, Professor of Physics, University of Massachusetts, Amherst; Dr. Nancy B. Songer, Professor of Education, University of Michigan; and Dr. Christopher J. Dede, Timothy F. Wirth Professor of Learning Technologies, Harvard University. The appendix includes answers to post-hearing questions. (YDS)

CLASSROOMS AS LABORATORIES: THE SCIENCE OF LEARNING MEETS THE PRACTICE OF TEACHING

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

MAY 10, 2001

Serial No. 107–7

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CLASSROOMS AS LABORATORIES: THE SCIENCE OF LEARNING MEETS THE PRACTICE OF TEACHING

THURSDAY, MAY 10, 2001

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:30 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Nick Smith [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
SUBCOMMITTEE ON RESEARCH
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, DC 20515

Hearing on

CLASSROOMS AS LABORATORIES: THE SCIENCE OF LEARNING MEETS THE PRACTICE OF TEACHING

Thursday, May 10, 2001

WITNESS LIST

Dr. Diane Halpern
Professor of Psychology,
California State University, San Bernardino

Dr. Jose Mestre
Professor of Physics,
University of Massachusetts, Amherst

Dr. Nancy Songer
Professor of Education,
University of Michigan

Dr. Chris Dede
Timothy E. Wirth Professor of Learning Technologies,
Harvard University

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HEARING CHARTER

CLASSROOMS AS LABORATORIES: THE SCIENCE OF LEARNING MEETS THE PRACTICE OF TEACHING

THURSDAY, MAY 10, 2001

10:30 AM TO 12:30 PM

2318 RAYBURN HOUSE OFFICE BUILDING

I. PURPOSE

On May 10, 2001 at 10:30 a.m., the House Science Committee's Subcommittee on Research will hold a hearing to examine the gap that currently exists between what is known about how people learn and the methods and materials educators use to teach. The fields of cognitive science and neuroscience have grown markedly due to an expanding repertoire of tools that enable researchers to understand how humans process, store and utilize information, yet educational materials and practices are rarely aligned to this knowledge. The subcommittee will consider recent reports from the National Academy of Sciences including *How People Learn: Bridging Research and Practice* and *Improving Student Learning* to better understand the recommendations for incorporating research into classroom practice. The hearing will help the Subcommittee refine ideas that are likely to be part of education legislation later this month.

II. BACKGROUND

In her book *Left Back: A Century of Failed School Reforms,* Diane Ravitch, an education historian and former Assistant Secretary for Education Research at the U.S. Department of Education, describes the succession of educational theories that constitute the pedagogical doctrine of the past 100 years. The book describes how various ideas about education have become mainstream theories usually without sufficient basis in research but with great hope that the idea will be the one that revolutionizes education, serves every student, and provides-the "magic bullet" solution to the problem of the day. Our capacity to conduct empirical research has expanded dramatically and there is a renewed call within the education community to incorporate insights from research into classroom practice.

A significant body of research and knowledge on the neurophysiology of learning that could have—but to date has not had—a significant impact on teaching and learning currently exists. For example, it is now known that memory for facts and events occurs in a different brain region than does memory for procedural information or skills. Further, memory for pictures is superior to that for words, but when pictures and words are combined, memory for both is enhanced. Research has also demonstrated that people do not remember facts or events in random sequence; rather, people organize events or facts into sequences that make sense to them for appropriate recall of information. Children normally have created their own conceptions or misconceptions of how things work, and instruction alone is not usually effective in replacing misconceptions with correct information. In fact, children frequently learn a new fact and regurgitate it accurately without ever replacing their incorrect misconception.

Dr. Diane Halpern, who will testify at the hearing, points out that children who learn that the earth is round frequently believe that there are two earths, the one that they learned about which is round and circulates around the sun and the other, flat earth on which they live. An understanding of the importance of children's misconceptions and the best techniques for helping children build correct understandings based on something they already understand is key to developing higher order thinking and learning in math and science.

Some education researchers have used this type of knowledge as a foundation to generate compelling hypotheses of how classroom instruction might be modified to utilize the current understanding of human perception and cognition. However, few of these hypotheses have been subjected to rigorous empirical testing. Instead, when testing is done at all, it is usually conducted in laboratory settings—rather than in actual classrooms—and quite often anecdotal evidence of changes in attitudes, perceptions or performance suffices as data. Only very rarely is research on particular education practices or methods taken further to examine which positive effects persist in the hands of less able teachers or within more diverse groups of students. Thus new education theories are often incorporated in classrooms on the basis of only tenuously supported data.

It is quite clear that sound, well-designed research is the key to advances in other areas of importance to Americans including medical sciences, transportation sciences, and computer and information science. Unfortunately, research has not had a similarly significant place in education. For example, the United States invests approximately 23 percent of its pharmaceutical spending on drug development and testing. In contrast, less than 0.03 percent of the $647.8 billion spent on K–12 education is invested in research of what educational techniques actually work and on ways to improve teaching. The 1997 President's Committee of Advisors on Science and Technology (PCAST) report, *The Use of Technology to Strengthen K–12 Education in the United States*, recommended that our education research investment be increased to 0.5 percent and that educational hypotheses be subjected to appropriately rigorous evaluation involving large numbers of children in authentic classroom environments. In addition, the report pointed out the need for researchers to empirically identify optimal educational practices and approaches based on subject area, student grade and ability level, teacher background, student interests and experiences, and environment, when undertaking this research.

National Research Council Reports on How People Learn and Improving Student Learning

In December 1998, the National Research Council released *How People Learn*, a report that synthesizes research on human learning. This report spoke of the important implications cognitive science could have for instructional materials and practices as well as on student assessment and the design of learning environments. The U.S. Department of Education's Office of Educational Research and Improvement (OERI) then posed the next question: What research and development could help incorporate the insights from the report into classroom practice?

In response to this question, a second expert panel met to discuss the links between research and practice and found that the influence of research is largely indirect and colored by public policy, public opinion, mass media reporting and even people's own experiences in school. The group published a document, *How People Learn: Bridging Research and Practice*, which included recommendations on providing research-based theories that are interpretable by classroom teachers and that have a direct impact on classroom instruction. In general, the panel recommended that research be "use-inspired," focused on issues of importance to teaching and learning, utilized to evaluate existing and new materials and practices, and conducted by teams rich with expertise in both research and practice.

While the *How People Learn* panels were working on recommendations for the future of education research, the National Research Council convened a second expert panel to develop a plan for a Strategic Education Research Program (SERP). In 1999 this group published *Improving Student Learning*, in which recommendations were made to establish four large "networks" assembled around major questions related to learning and instruction, student motivation, transformation of schools, and utilization of research in schools. SERP has recently convened a second panel to develop the details of the plan and to further expand upon the network concept.

Interagency Education Research Initiative

Following the 1997 PCAST report, the Interagency Education Research Initiative was developed by the National Science Foundation (NSF), the Department of Education's Office of Educational Research (OERI), and the National Institute of Child Health and Human Development (NICHD). The goal of IERI is to improve pre-K–12 student learning and achievement in reading, mathematics, and science by supporting rigorous, interdisciplinary research on large-scale implementations of promising educational practices and technologies in complex and varied learning environments. IERI supports work that moves beyond controlled laboratory assessment to study and evaluate methods and materials within authentic classroom environments. The IERI program focuses on the early learning of foundational skills and the transition to increasingly complex science and mathematics learning.

The first round of IERI grants, awarded in FY 2000, focused largely on foundation reading skills and linked basic knowledge about linguistics and cognition to instructional methods that lead to reading fluency, phonemic awareness, word reading, and comprehension. The 10-year debate on the effectiveness of whole language reading versus phonetic reading yielded a considerable research base on language skill acquisition and reading instruction. The current IERI grants make use of this research on reading to better understand optimal classroom reading instruction and to explore the potential transfer of reading skills to enhance student achievement in mathematics and science.

The knowledge base on student learning of mathematics and science is not nearly as robust as that which exists for literacy and student acquisition of reading skills.

Therefore a primary focus for the FY 2001 IERI awards will be the transition to developing mathematical and scientific knowledge and problem solving skills in children. Studies will focus on the development and full implementation of math and science instructional methods and materials and further exploration of how students learn basic and complex math and science, how students utilize basic skills to solve complex problems, and how students learn to integrate information across disciplines.

All IERI grants must employ interdisciplinary research teams and sound research methodology to explore the development of linkages between research knowledge and classroom practice and to investigate the role of technology in instruction and/or assessment. FY 2001 funding for the IERI program is anticipated to total $48 million: $25 million from NSF, $20 million from Department of Education and $3 million from NICHD. All three agencies work to coordinate research and dissemination efforts.

The National Science Foundation's Role in Education Research

Beyond IERI, the National Science Foundation has a variety of on-going programs aimed at both cognitive science research and linkages between this research and classroom practice. Within the Social, Behavioral and Economics (SBE) Directorate, the Behavioral and Cognitive Sciences Division (BCS) of the National Science Foundation has several programs aimed at understanding how children learn and how this learning varies with context. In FY 2001, programs within SBE that specifically address cognition and education research include The 21st Century Children's Research Initiative ($2 million), Human Cognition and Perception ($6.4 million), Linguistics ($5.4 million), and Developmental and Learning Sciences ($2.2 million). Within the Education and Human Resources Directorate, the Research on Learning and Education (ROLE) program provides $40 million in support for investigations that target the linkages between research and education practice.

III. Witnesses

Witnesses testifying at this hearing include cognitive scientists, education researchers, and practitioners who will talk about both the barriers and the promise of bridging the gap between education research and practice.

- Dr. Diane Halpern will give testimony about the current state of the field and about the recommendations for fostering applied education research as outlined in *How People Learn* and in *Improving Student Learning*. Dr. Halpern is a Professor of Psychology at the California State University, San Bernardino, and recently convened a national conference, *Applying the Science of Learning,* to examine the state and future of science-based education research.
- Dr. Jose Mestre will discuss his contributions to the *How People Learn* report and his experience in applying the findings of cognitive science to the practice of teaching physics. He will also discuss the need to better train teachers to utilize research in working with students and in evaluating students' misconceptions about science. Dr. Mestre is a theoretical nuclear physicist who has worked as a cognitive scientist for more than 20 years within the Research Physics Department at University of Massachusetts, Amherst.
- Dr. Nancy Songer will describe her work, funded through the Interagency Education Research Initiative, to establish a model and conduct a comprehensive, large-scale, longitudinal study of effective curricular materials and teaching practices related to teaching biology. Dr. Songer is a Professor of Education at the University of Michigan.
- Dr. Chris Dede will discuss the special issues related to the need for more research in the effective use of technology in instruction, teacher preparation, and student assessment. Dr. Dede is the Timothy E. Wirth Professor of Learning Technologies at Harvard University and is a published researcher on the use of current and evolving technologies in education.

IV. Questions

1. Where is the current state of knowledge on how people learn the strongest and in what areas do significant research gaps exist? Where are the biggest gaps between what we know about learning and what we know about teaching? What research programs should be undertaken to help close these gaps?
2. How well do we understand how children learn math or science as compared to how they learn reading and do we currently have instructional practices, standards and materials that are in line with that understanding?

3. How prepared are schools and teachers to take advantage of computers and other technology in classroom instruction and student assessment?
4. What barriers currently exist between education researchers and education practitioners that block the transfer of knowledge from one group to the next and how might we remove those barriers and facilitate partnerships between these two groups?
5. If we were to establish research centers linking education researchers with education practitioners for the purpose of developing and assessing best practices and materials, how should they be structured?
6. How should teacher training and certification programs be restructured so that elementary, middle and high school teachers are better prepared to teach science and mathematics?

Chairman SMITH. The Subcommittee on Research of the Science Committee will come to order. Good morning, everyone, and welcome to our second hearing in a series dedicated to kindergarten through 12th grade math and science education. Today, the Subcommittee is going to focus on developing the linkages, the connections, between the science of learning and the practice of teaching. Advances in medical imaging instruments have provided neuroscientists and cognitive scientists with unprecedented access to the human brain.

The bells, for everybody's information, means that in approximately 9 minutes, we will be recessing to go vote on this rule that is before us.

Again, advances in medical imaging instruments have provided neuroscientists and cognitive scientists with unprecedented access to the human brain, enabling researchers to better understand how the brain collects, processes, stores, and recalls information and recalls experiences and memories. For example, cognitive scientists who study how the brain functions during learning now know that different regions of the brain are involved in learning facts versus skills, and in learning a second language as a child versus and adult.

Experts now understand that children don't begin school as an empty vessel waiting to be filled with knowledge. Rather, children begin school with a vast array of conceptions and misconceptions about the world around them and they will construct new learning around these sometimes erroneous beliefs.

But this kind of knowledge of how children learn has not been widely or effectively translated to instructional materials and practices and little research really exists that is directly useful for classroom teachers. Research is often conducted in controlled laboratories rather than in authentic classrooms and the research questions are infrequently derived from current classroom concerns and difficulties. Further, teachers are generally untrained in much of the research and don't know how to interpret or transfer such technical research data to practical classroom applications.

We need to bridge the gap that exists between education and this kind of research and practice so that teachers have access to proven materials and practices that are aligned with current understanding of how the brain works. We must engage a range of professionals, including cognitive scientists, psychologists, teachers, biologists, chemists, physicists, certainly mathematicians, and policy makers in this quest for better understanding of the science of teaching.

Like medicine, education, it seems to me, requires significant investment in rigorous, empirical research to facilitate the development of effective educational tools, materials, and practices. In her paper, "What if Research Really Mattered?", Diane Ravitch applied the education model to medicine and imagined how her own diagnosis and treatment of an ailment might have been different if her doctors were trained in the same way that educators are trained.

Would she—she would have been accurately diagnosed, since some would see a diagnosis as a stigmatizing label to be avoided at all costs? Would her doctors agree on the validity of the CAT scan as an assessment tool? Would they say that there simply isn't enough time or money to provide treatment based on the diagnosis anyway? At the end of this somewhat, maybe, tongue-in-cheek exercise, Dr. Ravitch concluded that educators have something to learn from physicians. And while medicine might have its share of quacks, on the whole, physicians have canons of scientific validity to protect innocent patients from unproven remedies and specious theories.

This parody, I think, is actually quite sobering when one considers the impact that the lack of research on teaching has on the lives of millions of children—certainly, all children. We want to explore the current state of the field and examine the gap that exists between cognitive science, education research, and actual classroom teaching. We will hear about the National Research Council recommendations for fostering problem-focused classroom research on teaching and learning and will hear about examples of collaborative research projects that transcend traditional barriers to advance science-based teaching.

I want to thank all of the witnesses today, look forward to your testimony.

[The prepared statement of Mr. Smith follows:]

PREPARED OPENING STATEMENT OF CHAIRMAN NICK SMITH

Good morning and welcome to our second hearing in a series dedicated to U.S. K–12th grade math and science education. Today the Subcommittee focuses on developing linkages between the science of learning and the practice of teaching.

Advances in medical imaging instruments have provided neuroscientists and cognitive scientists with unprecedented access to the human brain, enabling researchers to better understand how the brain collects, processes, stores, and recalls information, experiences and memories. For example, cognitive scientists who study how the brain functions during learning now know that different regions of the brain are involved in learning facts versus skills, and in learning a second languages as a child versus an adult. Experts now understand that children don't begin school as an empty vessel waiting to be filled with knowledge; rather, children begin school with a vast array of conceptions and misconceptions about the world around them and they will construct new learning around these sometimes erroneous beliefs.

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I want to thank the witnesses for appearing today, and I look forward to your testimony.

Chairman SMITH. And with that, Representative Johnson, would you prefer to start your comments now or when we return?

Ms. JOHNSON. I can probably get it done in 5 minutes.

Chairman SMITH. Okay. Please proceed.

Ms. JOHNSON. Thank you very much, Mr. Chairman. The main themes that emerged from the previous hearing of the Research Subcommittee on education research in the fall of '99 were that education research is underfunded, of variable quality, and largely ignored by educational practitioners. These findings were largely consistent with the results of a 1996 review of Federal education research activities by the National Research Council, the NRC.

Overall, the NRC concluded, and I quote, "The picture of current activities that emerges is a potpourri of programs and activities that together represented enormous expenditure of energy and political capital, but that exhibit an equally striking lack of coordination." Further, the NRC characterized the agencies as having had a lack of focus, spreading that limited resources so thinly that mediocrity was almost assured. Further, the NRC pointed to a paucity of mechanisms for translating results of successful research into practice. That is, few practitioners have access to, or the ability to use, research results.

There are no effective avenues for conveying the most important research findings and systematically training practitioners in how to apply the findings. And, finally, there is the cultural divide between researchers and practitioners exacerbated by the absence of a reward system to encourage researchers to work with practitioners. I hope our witnesses today will be able to report that things have improved since the NRC report was issued. There certainly seems to be a lot of room for improvement.

One important focus of this hearing is to explore ways that the President's budget proposal for a new education initiative at NSF could be used to help address educational research needs. This 5-year, $1 billion initiative is intended to establish partnerships between schools and universities to improve science and math education. I will be very interested in hearing the comments and recommendations of our Panel on what are the greatest research needs to be addressed.

And equally important, I solicit your views on how these partnerships could be structured to encourage collaboration among those who perform basic research in cognition and human learning, those who perform educational research and teachers and school administrators and developers of educational materials.

I am also interested in the Panel's views on recommendations from the 1997 report of the President's Committee of Advisors on Science and Technology. The recommendation, which was also endorsed by the Congressionally mandated Web-based Education

Commission, was for a major research program to carry out large-scale experiments to identify and quantify effective educational technologies. The basic idea is that the schools need better information on what works to guide the substantial investment that is required to implement educational technology. There is wide agreement that improving K through 12 education is essential to the Nation's future well-being. It is past time to end their parent disconnect between educational practice and the knowledge provided by basic research on human development and learning.

Educational reform will have a much greater chance to succeed if informed by such knowledge and accompanied by sufficient investment in large-scale, rigorous, well-controlled, empirical research to determine what works in the classroom.

I congratulate my Chairman for calling this hearing, and I am pleased to join him in welcoming our witnesses. There—this—there really is no subject of importance for the Subcommittee to consider any more than this, and I look forward to the discussion. Thank you.

[The prepared statement of Ms. Johnson follows:]

PREPARED OPENING STATEMENT OF EDDIE BERNICE JOHNSON

The main themes that emerged from the previous hearing of the Research Subcommittee on education research in the Fall of 1999 were that education research is under-funded, of variable quality, and largely ignored by educational practitioners.

These findings were largely consistent with the results of a 1996 review of federal education research activities by the National Research Council (NRC). Overall, the NRC concluded, and I quote, "the picture of current activities that emerges is a potpourri of programs and activities that together represent an enormous expenditure of energy and political capital but that exhibit an equally striking lack of coordination." Further, the NRC characterized the agencies as having had a lack of focus, spreading their limited resources "so thinly that mediocrity was almost assured."

Further, the NRC pointed to a paucity of mechanisms for translating the results of successful research into practice. That is, few practitioners have access to or the ability to use research results. There are no effective avenues for conveying the most important research findings and systematically training practitioners in how to apply the findings. And finally, there is the cultural divide between researchers and practitioners, exacerbated by the absence of a reward system to encourage researchers to work with practitioners.

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I am also interested in the panel's views on a recommendation from the 1997 report of the President's Committee of Advisors on Science and Technology. The recommendation, which was also endorsed by the congressionally mandated Web-Based Education Commission, was for a major research program to carry out large-scale experiments to identify and quantify effective educational technologies. The basic idea is that schools need better information on what works to guide the substantial investment that is required to implement educational technology.

There is wide agreement that improving K–12 education is central to the nation's future well being. It is past time to end the apparent disconnect between educational practice and the knowledge provided by basic research on human development and learning. Educational reform will have a much greater chance to succeed if informed by such knowledge and accompanied by sufficient investment in large-scale, rigorous, well-controlled empirical research to determine what works in the classroom.

I congratulate the Chairman for calling this hearing, and I am pleased to join him in welcoming our witnesses. There is no subject of more importance for the Subcommittee to consider, and I look forward to our discussion.

Chairman SMITH. Thank you. And for the information of the witnesses and our guests at the hearing today, we will be—there is just one vote, so we will be gone approximately 12 minutes and then we will reconvene. And with that, the Committee stands in recess.

[Recess]

Chairman SMITH. The Subcommittee will reconvene. If there is no objection, any other opening statements by members will be added to the record. Without objection, it is so ordered. At this time, I would like to introduce our Panel. Our first witness, Dr. Diane Halpern, will give testimony about the current state of the field and about the recommendations for fostering applied education research as outlined in recent reports from the National Academy of Science. Dr. Halpern is a Professor of Psychology at the California State University at San Bernardino, and recently convened a national conference to examine the state and future of science-based education research.

Dr. Jose Mestre will discuss his contributions to the field of education research and his experience in applying the findings of cognitive science to the practice of teaching physics. He will also discuss the need to better train teachers to utilize research in working with students and in evaluating students' misconceptions about science. Dr. Mestre is a Theoretical Nuclear Physicist who has worked as a cognitive scientist for more than 20 years within the Research Physics Department at the University of Massachusetts at Amherst.

Our third witness is Dr. Nancy Songer. And Dr. Songer will describe her work funded through the interagency education research initiative to establish a model and conduct a comprehensive and large-scale study of effective circular materials and curricular—curriculum—curricular materials and teaching practices related to teaching biology. Dr. Songer is a Professor of Education at the University of Michigan.

Finally, Dr. Chris Dede is going to discuss the special issues related to the need for more research and the effective use of technology and instruction, teacher preparation, and student assessment. Dr. Dede is the Timothy E. Wirth Professor of Learning Technologies at Harvard University and is a published researcher on the use of current and evolving technologies and education. So, again, welcome.

As our panelists may know, your spoken testimony is limited to 5 minutes, after which the members of the Committee will have 5 minutes to ask questions, and your full text of your testimony will be included in the record. And with that, Dr. Halpern, we will start with you.

STATEMENT OF DR. DIANE HALPERN, PROFESSOR OF PSYCHOLOGY, CALIFORNIA STATE UNIVERSITY, SAN BERNARDINO

Dr. HALPERN. Thank you for inviting me to join you today. My area is cognitive psychology. Cognitive psychology is the empirical branch of psychology. We use both carefully controlled laboratory studies and we also conduct studies out in the real world. Cognitive psychologists study how people think, how they learn, how they remember, how they formulate and solve problems, and how they reason.

We already have considerable knowledge about powerful learning strategies that can be used to promote long-term retention and transfer. And, as Mr. Smith has already mentioned, despite all of the gains that we have made in understanding what happens when people learn, most teachers have learned relatively little from cognitive psychology.

We know that if we are interested in school reform, in helping people learn better, we need a successful pedagogy, a theory of how people learn, to guide us—one that can serve as a basis for the enhancement of learning and it has to incorporate ideas about the way in which learners organize knowledge, the way they represent it internally, and the way these representations change and resist change when new information is encountered. We know that the gap between empirically validated theory and practice is wide. That, in fact, very little of what we know is really being used.

Let me give you some ideas about what I mean when I talk about the principles that should be guiding how we design education. We know that what and how much gets learned in any situation depends very heavily on prior knowledge and experience. And we use the term construction of knowledge because each learner builds meaning based on what is already known. And just for an example, when children and naïve adults learn, for example, that the world is round, they first build a notion of sort of a pancake-shaped earth. Then it can get changed into the idea of a ball that is cut so we can walk on it without falling. And, in fact, what happens is they are often able to put the correct answer on an exam, give the appearance of understanding, whereas, in fact, their understanding is, at best, shallow. And we are also mislead—often mislead into believing that learning is better than it really is.

We have mental models or beliefs about the world. This is the way people think. And we have these for a wide variety of complex phenomena. I have examples from physics. We have examples from our understanding of the social world, for example, stereotypes about people. And these models are very resistant to change. Cognitive psychologists and others have developed diagnostic assessment programs that provide understanding about what each learner's more complex model is. And then, based on the way the learner responds, it allows us to redirect learning activity and allows for the correction of some of these errors.

We know that learning is influenced by our students' and our own epistemologies, theories about learning. What our students believe to be true about learning, what we believe to be true about learning. Academic motivation is related to these beliefs about how people learn. We also have literature showing that there are ethnic and other group differences in these epistemologies.

In the United States, we are facing a very serious shortage of scientists, and the level of understanding of scientific principles among the general public is abysmally low. Yet, many learners are avoiding course work. They are opting out of it as much as possible in the sciences, math, and related fields. When you ask them why, they say they can't learn in these areas. What they are really saying is, that they find learning in these academic disciplines to be difficult. They don't know that it should be difficult. That some learning, in fact, is easy; some is implicit, and some is effortful, perhaps even aversive. But with additional learning, effortful becomes easier. And that there is no single set of learning principles that applies in all situations because learning and remembering are not univariate concepts.

Another principle that I am talking about is that experience alone is a poor teacher. We have countless examples where what we learn from experience is, in fact, systematically wrong. We need to direct learning activities in ways that are going to allow for systematic kinds of feedback. Very often we end up with great confidence in our erroneous beliefs based on our everyday kinds of experiences where we seek to confirm our models about what we believe to be true.

It is important that, in thinking about the redesign of education, that we, in fact, teach for transfer and we teach for long-term retention. And we have methods and ways that we know will, in fact, make transfer and long-term retention much more likely. My own particular interest is in the enhancement of critical thinking skills and the idea that we teach them in a way to transfer across context and long after graduation. The problem is, we are always teaching for some time into the future and for a test that we are not giving, and that is the sorts of ideas that need to be aiding how we rethink what we are doing about education.

If we are talking about making changes, that also means that we are going to have to have some assessments to see if, in fact, we are heading in the right direction. When you care about something, you measure it. Assessment is a term that conveys multiple meanings to different audiences. There is assessment for the purpose of improving teaching and learning. There is assessment for the purpose of certifying the level of knowledge that a learner has. There is assessment for the evaluation of the teacher or the program or the district. These are all qualitatively different meanings for the term "assessment".

I believe that much of the heated debate, and the debate is very heated over the questions of assessment, could be resolved if the people involved in the debate understood that they are talking about assessment for different purposes. And it is the purpose that should be guiding how the assessment is done.

We have a critical need for research, research that can scale up to large samples at multiple sites with a variety of learning. We have a lot of small-scale research. What we don't have is the scale up of the principles that we see either in the lab or in small settings. We need research that can employ research designs that support more causal inferences. And we need research that will last long enough into the future so that long-term retention and real-world transfer is assessed and we have to encourage responsible taking. And, as my last thing, is that this is the most important task we face as a society. Thank you.

[The prepared statement of Dr. Halpern follows:]

PREPARED STATEMENT OF DIANE F. HALPERN

Applying the Science of Learning: Using the Principles of Cognitive Psychology To Enhance Teaching and Learning

Thank you for inviting me to join you in your deliberations about ways to apply principles from the science of learning to enhance teaching and learning. I am delighted and honored to be here. Unfortunately, you gave me an almost impossible assignment—in about five minutes, I am supposed to provide a useful summary of what we know about human learning and cognition with suggestions for future research. In the short time allocated, I plan to share some of my excitement about advancements in the learning sciences with you and suggest some ways to translate our knowledge of human cognition into meaningful school reform with the hope that you will continue to explore the findings and ideas at some later time.

My academic area is cognitive psychology. Cognitive psychology is the empirical branch of psychology that deals with questions about how people think, learn, and remember. Cognitive psychologists study how people acquire, utilize, organize, and retrieve information. We study topics like memory, decision making, problem identification and solving, critical thinking, and reasoning. It is clear that a successful pedagogy that can serve as a basis for the enhancement of learning will have to incorporate ideas about the way in which learners organize knowledge and internally represent it, and the way these representations change and resist change when new information is encountered. Despite all of the gains that we have made in understanding what happens when people learn, most teachers "have gained relatively little from cognitive psychology" (Donald Schoen, *The Reflective Practitioner,* 1983). It seems that even cognitive psychologists apply very little of what they know about their academic discipline to their teaching. The gap between empirically validated theory and practice is wide. This idea first came to me as I sat through a deadly dull three-hour lecture on the shortness of the human attention span.

Here are a few examples of cognitive principles that should be guiding our design of learning activities:

1. *What and how much gets learned in any situation depends heavily on prior knowledge and experience. Psychologists use the term "construction of knowledge" because each learner builds meaning using what is already known.* For example, in an explanation of this principle in "How People Learn," we are told about a fish who learns about the dry world from a bird. When the bird describes beings who can walk upright and breathe air, the fish imagines fish-looking people walking on their tails, with both gills surrounded with water and lungs filled with air. The comprehension process is similar to that used when children learn that the world is round; they replace their pancake-shaped view of the earth with a ball that has been cut in half, so that we can walk on the flat cut surface without falling off. In other words, the best predictor of what is learned from at the completion of a lesson, course, or program of study is what the learner thinks and knows at the start of the lesson, course, or program of study.

2. *We maintain mental models (beliefs) for a wide variety of complex phenomena including those we encounter in the physical world (e.g., moving objects) and social world (e.g., stereotypes about members of groups) because, for the most part, they make sense to us. Our models of the world "work," and thus are difficult to change. Individuals beliefs about the world are organized into mental models that make sense and "work"—that is, do a reasonably good job in their day-to-day life.*

Consider this: In a random telephone survey conducted by the Public Opinion Laboratory at Northern Illinois, 21% of the over 2000 adults who responded to the survey believe that the sun resolves around the earth, and an additional 7% did not know which revolves around which. Didn't most of these adults learn somewhere that for over 400 years the scientific community unanimously determined that the earth revolves around the sun? Although we cannot be sure, I would guess that most of these adults learned this fact, but never altered their mental models of planetary motion because their everyday observations don't support it. We see the sun "moving" across the sky as morning turns into night. The earth-centric view of the universe makes sense according to the naive model that is easily constructed and tested and confirmed on a daily basis. In order to change an individual's mental model, we need to design instruction so that the errors in naive models are exposed and the benefits of the new model are obvious. Cognitive psychologists and others have diagnostic assessment models that provide information about each learner's understanding, and based on the way learners respond to questions designed to probe their understanding, teachers can redirect learning activities that correct these errors.

3. Learning is influenced by our students' and our own epistemologies (theories about learning). Academic motivation is related to beliefs about learning.

Many students believe that they cannot "do math," or understand science, or write poetry, or succeed in some other academic discipline. When you ask them about this belief, you find that what they really are saying is that they believe that learning should be easy, but when they learn in these disciplines, it is effortful. What they don't know is that learning and remembering involve multiple, interdependent processes. Some types of learning occur implicitly, that is without conscious awareness. Other types of learning are very easy, and other types of learning are effortful, perhaps even painful and aversive, such as learning the names of the facial nerves or how to "do" long division. It is only after they invest in the hard work of learning that additional learning in these fields becomes easy and more automatic. There is no single set of learning principles that will always work. If I were learning how to ride a unicycle, I would need to practice on a unicycle, no amount of expert explanation would substitute for my getting on the unicycle and pedaling; but I do not have to experience different events in history in order to "know" them. The best way to learn and recall something will depend, in part, on what it is you want to learn and recall as well as what you already know.

4. Experience alone is a poor teacher. There are countless examples where what we learn from experience is, in fact, systematically wrong. For example, most jurists believe that they can tell from a person's demeanor whether she or he is telling the truth. In fact, they cannot. Therapists believe that a particular intervention has worked when a client improves after that intervention; of course, if most clients enter therapy at times of crisis, then improvement is likely no matter what intervention is taken because of the ubiquitous effect of regression to the mean. If a client does not improve, then therapists reason that he or she was too sick to benefit from the good treatment. There are countless examples of this sort of erroneous thinking, where our beliefs about the world are maintained and strengthened despite the fact that they are wrong. We end up with great confidence in our erroneous beliefs.

This is important because there is a popular belief that all learning and learning assessments should be "authentic"—a term that I don't particularly like. I'd settle for phony learning if what was learned met the tests of long-term retention, retrieval when needed, and flexible recall and use of the information that was learned so it can be used creatively—regardless of how it was learned. Authentic situations are often not optimal for good learning. What is missing from most authentic situations and from most real-life situations is systematic and corrective feedback about the consequences of various actions. When jurists have many experiences where they believe that they can tell if someone is lying *and* they receive feedback as to whether or not the individual is lying, they can learn that they are not good judges of truth telling. In real life, the systematic feedback is usually missing, so they continue to believe that they are good at the task of identifying liars when, in fact, they are not. Similarly, in the absence of reliable and regular feedback, we tend to believe that our interpretations of social events are accurate or the reasoning behind a political belief system is valid when it may not be.

Let me quickly list a few more examples of ways that can be applying cognitive principles to our teaching and learning.

- Virtually all science courses, especially at the introductory level, involve a lecture portion where a lone teacher mostly talks (and writes on the board) and learners take notes—a satisfactory arrangement for learning if the desired outcome is to produce learners who can repeat or recognize the information presented, but one of the worst arrangements for the promotion of in-depth understanding. In this example, the problem is that both the faculty and students believe that achieving a high score on a recognition test (i.e., multiple choice exam in which the questions tap lower level cognitive processes) or a test that requires only repetition of course material is evidence of "good learning." Unfortunately, it is possible for students to achieve a high score on tests like these and not be able to recognize that a concept applies in a slightly altered context or be able to apply a concept at some time in the future.

- Laboratory exercises are mostly "canned," requiring very little original thought by the learners and few surprises for anyone, thus bearing little resemblance to the cognitive processes needed in real research laboratories. The more creative aspects of research, including the generation of a genuine question and the multiple decision points encountered in the research process are invisible to students in most laboratory courses, especially at the introductory level, where the vast majority of college students complete their formal science education. It is impossible to estimate the number of potential scientists and scientifically informed citizens who are lost at this level because they fail to see any excitement in research, but there are many reasons to believe that it is a large number.
- Asking learners to recall some information leads to selective "forgetting" for other related information that they were not asked to recall. Thus, the act of remembering strengthens some memory traces and weakens others, a fact that should influence how we test students. Few college faculty are aware of this effect and inadvertently are creating learning activities that actually cause forgetting for information that want students to retain. When students are tested frequently, they receive higher scores than students who are tested infrequently, thus creating the impression that frequent testing is a sound educational practice. Conscientious professors will often use frequent testing because they believe that the high scores achieved on these tests show that frequent testing is a sound educational practice. But, frequent testing also leads to overconfidence in learners who erroneously believe that their long-term retention for the information will be better than it actually is, a belief that should lead them to put less time and effort into studying the material for future recall This is another example where the short-term benefits of an educational practice masks the long-term detriments associated with it.

Teaching for Transfer

The sole reason why we have schools and universities, that is formal settings designed for learning activities is that we expect that learning will transfer. Information learned in one context can transfer to a different context, but we need to teach in ways that encourage transfer. Because of my interest in and commitment to helping students improve their ability to think critically, this is one topic about which I have very strong feelings. The purpose of formal education is transfer. We teach students how to write and think well in the belief that they will use these skills when they are not in school. The truth is sometimes they do and sometimes they don't.

Let's consider a simple concept like correlation. Most students who have taken courses in the social and behavioral sciences or statistics can tell you that a correlation between two variables does not necessarily mean that one caused the change in the other. Most students who have had course work on this topic can compute a correlation coefficient for a set of data and provide examples of positive and negatively correlated variables. They can explain the oft-cited example that as the number of churches increases in a city so does the number of prostitutes, but that this relationship doesn't mean that the increase in number of churches caused the increase in number of prostitutes. But what happens when they are sitting at their kitchen table and read in the newspaper about a study that found that students who attended preschool were better readers by the end of first grade? Many of these same students don't recognize the likelihood that attending preschool did not necessarily cause the first graders to be better readers. But our students can be taught to recognize and apply concepts, like correlational reasoning, that are learned in school in real world settings.

The frequent use of real-life examples will help students to recognize these principles when they encounter them out of school, especially when a wide variety of examples are used and informative feedback is provided. There is a strong research base that supports this statement. Of course, a teacher who returns to the same topic with real life examples throughout the semester will "cover" less material than one who goes on to another topic as soon as her students can compute the correlation coefficient and explain that correlation is not cause. We need to give more thought to what we want students to know and be able to do when they finish our courses.

With some consideration of what sort of information students will need to know and in what settings, principles to enhance transfer and retrieval can be incorporated into every learning activity.

Assessing Learning Outcomes

We need assessments of learning that are consistent with their intended use. Assessment is a term with multiple meanings. Assessment designed to provide feedback that will improve teaching and learning is different from assessment for the purpose of certifying a level of knowledge or skill for the learner, which is also different from assessment for the purpose of evaluating the instructor or the instructor's system or state. I believe that much of the heated debate over assessment would be resolved if those involved in the debate realized that they are often talking about assessment for different purposes and the type of assessment needs to match its intended use.

Research Needed

We need research that can "scale up," by that I mean research designs for large and diverse groups of learners, multiple researchers and teachers, with at least a quasi-randomized design that will allow stronger causal inferences than most educational research designs. Educational research needs to be funded for longer periods of time so that long-term retention and transfer can be assessed. Long-term retention and transfer are the reasons for education, but we cannot determine the effectiveness of any educational application or intervention if the funding runs out before the students leap the many educational gaps, where increasing numbers are unable to bridge from high school to post-secondary school and from school to work.

We need to invest in dissemination projects with as much care and planning as we put into the research itself. There need to be rewards for good educational practices along with positive outcomes for researchers and teachers who are willing to take risks, even when the knowledge gained from those risks is that some method did not work as hoped.

There are, of course, numerous other examples that I could have used to make my point that knowledge of how people learn, think, and remember should at the heart of educational reform. I am happy to provide suggested readings for anyone who would like to learn more or check my conclusion that, with appropriate instruction, we can improve how people learn, remember, and think.

In closing, I'd like to add that enhancing student learning is the most important task we face as a society. Work place and citizenship skills are more complex that ever before; a thinking, educated citizenry is our best hope for the future. We can do a better job of educating our country's most precious commodity—smart, educated adults who can cope with and chart the direction of the change. The rate at which knowledge has been growing is exponential and the most valued asset of any society in the coming decades is a knowledgeable, thinking citizenry—human capital is our wisest investment. More than ever, we need to prepare students to learn efficiently and to think critically, so that the United States can remain competitive and cooperative in the 21st century.

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An annotated reference list and numerous related documents can be found at http://asl.csusb.edu

I thank the Spencer Foundation and Marshall-Reynolds Trust for their support of a retreat on "Applying the Science of Learning."

BIOGRAPHY FOR DIANE F. HALPERN

POSITION AND TITLE:

Professor, Department of Psychologyl, California State University, San Bernardino

EDUCATION:

1979 Ph.D., Psychology, University of Cincinnati
1977 M.A., Psychology, University of Cincinnati
1973 M.A., Psychology, Temple University
1969 B.A., Psychology, University of Pennsylvania

AWARDS and HONORS (selected)

1999–2000 Wang Family Excellence Award (selected from among 10,000 faculty)
1999 American Psychological Foundation Award for Distinguished Teaching
1999 Eminent Women in Psychology
1998 James Madison University, Distinguished Visiting Scholar Award
1996–1997 Distinguished Career Contributions to Education and Training
1995 Rockefeller Foundation Scholar-In-Residence
1994 Fulbright Scholar Award
1992 Birkett Williams Memorial Lecture Award
1991 G. Stanley Hall Lecture
1989 Fellow, American Psychological Association
1988 Outstanding Alumni Award
1987 Educational Equity Award
1986 Silver Medal Winner, Council for the Advancement and Support of Education
1986 Outstanding Professor Award

PROFESSIONAL AFFILIATIONS

American Association for Higher Education
American Psychological Association (Fellow Status)
American Psychological Society (Charter Member; Fellow Status)
Psychonomic Society
Western Psychological Association (Fellow Status, President 1999–2000)

OTHER PROFESSIONAL EXPERIENCE

Editorial Board, *Journal of Experimental Psychology: Applied.* 2001–2004
Editorial Board, *Brain and Cognition,* 1999–2002
Editorial Board, *Journal of Educational Psychology,* 1991–1996
Editorial Board, *Journal of Experimental Psychology: General,* 1989–1996
American Psychological Association, Division 1: General Psychology, 1996–President
Division 2: Society for the Teaching of Psychology, 1997–President
American Psychological Society, Co-Chair (with Milton Hakel, Bowling Green State University), Work group on Education, 1999–2002

SPECIAL PROJECTS

People's Republic of China, Hong Kong 2000–2001. Prepared "expert report" for the Hong Kong Department of Education for use in a lawsuit concerning discriminatory use of test scores and grades for placement in secondary schools.

Grants—Funded Projects

PI, The Spencer Foundation: "Practicing What We Preach: Using the Principles of Cognitive Psychology to Enhance Learning" 2000–2001.

PI, Marshall-Reynolds Trust: "Science Based Teaching" 2000–2001.

PI and Project/Conference Coordinator on project to translate the science of learning into an action plan for the redesign of higher education. Project is conducted under the auspices of the American Psychological Society and includes an invited working retreat of 35 prominent scientists held in March, 2001, and a volume of proceedings.

View on-line site: http://asl.csusb.edu

College Board, New York

Research project entitled, "new initiatives in admissions testing." 2000–2001. Multiphase project that is examining new sorts of measures of achievement/ability. Phase II of the project is expected to begin in Spring 2001 when I will be conducting research on several possible assessments that could be used for admissions testing.

U.S. Army Research Institute

Research and educational project designed to increase the critical thinking abilities in the U.S. military. Presentation and planning at Ft. Leavenworth, December 2000.

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CALIFORNIA STATE UNIVERSITY
SAN BERNARDINO
5500 University Parkway, San Bernardino, CA 92407-2397

COLLEGE OF SOCIAL AND
BEHAVIORAL SCIENCES
Department of Psychology
(909) 880-5570
fax: (909) 880-7003

May 10, 2001

The Honorable Chairman Sherwood L. Boehlert,
Chair, U.S. House of Representatives
Committee on Science
Research Subcommittee
B-374 Rayburn Building
Washington, D.C. 20515

RE: **Disclosure of Federal Government Funding**

Dear Chairman Boehlert:

Thank you for the invitation to provide testimony to the U.S. House of Representatives Committee on Science, Research Subcommittee at hearings that address the topic "Classrooms as Laboratories: The Science of Learning Meets the Practice of Teaching." In accord with the regulations and procedures for testifying before Congress, I hereby notify you that I have not received any federal funding related to this topic.

Sincerely yours,

Diane F. Halpern

Diane F. Halpern, Ph.D.
Professor of Psychology

The California State University
Bakersfield • Channel Islands • Chico • Dominguez Hills • Fresno • Fullerton • Hayward • Humboldt • Long Beach • Los Angeles • Maritime Academy
Monterey Bay • Northridge • Pomona • Sacramento • San Bernardino • San Diego • San Francisco • San Jose • San Luis Obispo • San Marcos • Sonoma • Stanislaus

Chairman SMITH. Thank you. Dr. Mestre.

STATEMENT OF DR. JOSE MESTRE, PROFESSOR OF PHYSICS, UNIVERSITY OF MASSACHUSETTS, AMHERT

Dr. MESTRE. Thank you, Mr. Chairman, for inviting me to testify, and I commend the Subcommittee for examining how the science of learning could be applied to improve students' learning and classroom practices.

I will comment on three areas, the first being the current state of knowledge about how people learn and where significant gaps exist in our knowledge. We know a lot about how people learn effectively and eventually develop expertise. We know how experts store and retrieve knowledge from memory and how they solve problems. We know about the different types of knowledge processed by experts and about their highly structured knowledge network and memory. We also know, as you said, Mr. Chairman, that learners are not empty vessels. Rather, they bring prior knowledge to any new learning situation and that prior knowledge filters and shapes new learning.

We also know about a rich-get-richer principle of learning. The more you know about a topic, the easier it is to learn more about that topic. Despite this vast knowledge base in the science of learning, there are also significant gaps. And I will now mention three areas where knowledge falls short. Knowledge transfer—so I guess I disagree with you somewhat. Transfer which refers to the flexible application of knowledge across different contexts is very difficult to achieve and very little is known about how one might structure teaching in ways to maximize transfer.

Two, pedagogical content knowledge. This terms refers to knowledge of content, such as math or physics, that is linked to knowledge about effective pedagogical techniques for teaching that content. Facilitating the acquisition of pedagogical content knowledge for teachers remains a major challenge, as well.

Three, assessment. More research is needed to develop and study assessments that both allow teachers to tailor instruction to meet students' needs and allow organizations and institutions to measure deep conceptual understanding and skilled problem-solving behavior. Setting research priorities that focus on these three areas would have a major impact on improving teachers' teaching and students' learning by promoting learning that lasts.

Next, I will comment on the training of teachers. Current practices for training pre-service and in-service teachers are in need of major revision. For pre-service teachers, there is a major mismatch between the kind of teaching we would like them to adopt and the kind of teaching they experience in science classes. Science content is taught by scientists using very traditional lecture methods and instructional innovation is taught by education faculty with little or no communication between these two groups. This practice is ineffective for developing pedagogical content knowledge. Perhaps, worse, it causes a major dilemma in teachers—should they teach science the way scientists taught them or should they teach the way educators said they should teach?

Further, the workshop structure commonly used for the continuing education of in-service teachers is not aligned with findings from the science of learning. In-service training practices are not designed to impact teacher's deep knowledge or content—of content or pedagogy. It is time to develop a science of pedagogy based on the science of learning and to begin examining pre-service and in-service practices through the lens of the science of learning.

There is another major problem that directly impacts on the education of pre-service teachers, namely, the way we train our science Ph.D.s. The training of science Ph.D.s consists of immersing the candidate in science content without demanding that she or he learn something about learners' cognitive development or pedagogy. Consequently, scientists know of no other way to teach than the way they were taught. Addressing this problem will come a long way in aligning the mismatch that I mentioned earlier.

Lastly, I will address how we might structure research and development in math and science education to ensure that we continue building the science learning infrastructure to make informed decisions about improving teaching and learning.

First and foremost, we need to realize that learning about learning involves human cognitive behavior, which is a very complex undertaking. We need to fight the misconception that studying education or fixing its problems is easy, simply because most of us went through the educational system and did very well at it. To learn about, and solve the complex problems in education today, we need to draw on the expertise and research methodologies from disciplines, such as cognitive science, education, psychology, neuroscience, linguistics, anthropology, and the disciplinary sciences. The types of collaborations I am suggesting will result in varied approaches to tackle varied problems.

Finally, there is a funding trend that may lead to undesirable outcomes. I would strongly argue that we not ignore the value of small grants to individual investigators. The trend I have seen at the National Science Foundation's Education and Human Resources directorate is to devote increasing resources to fund large projects requiring collaborations among a large number of individuals and institutions. Although large projects have a place in science and math education reform, we are not devoting enough resources to fund the single investigator in their projects.

We need to have the best science done by the best people, and this calls for opening up competitions to attract the best research possible. Presently, the resources at NSF's EHR directorate for funding research are too meager to build the research infrastructure necessary. If we neglect this need, we will soon outdistance our research knowledge base and be forced to make decisions about teaching and curriculum on art rather than science.

The field needs mechanisms to sustain and expand on the excellent body of research cited in the two recent reports on the science of learning from the National Research Council and not to stifle it by devoting all new resources to large projects. Thank you for this opportunity.

[The prepared statement of Dr. Mestre follows:]

PREPARED STATEMENT OF JOSE P. MESTRE

I would like to begin by thanking Chairman Smith for inviting me to testify before the Subcommittee on Research of the House Committee on Science. It is a pleasure to be here.

I commend the Subcommittee for taking up the issue of how to best deploy our extensive knowledge about human cognition to improve students' learning and classroom practices at this hearing on *Classroom as Laboratories: The Science of Learning Meets the Practice of Teaching.*

I'd like to begin with a few brief comments about my background that will help put my testimony in perspective. My Ph.D. is in theoretical nuclear physics, but upon graduation I changed fields to cognitive science because I found learning research more interesting than performing theoretical nuclear calculations. I began my new career as a cognitive scientist more than 20 years ago within a research physics department with the help of a federal grant. At that time nearly all physicists, and scientists, believed that "education" work belonged elsewhere—perhaps in a school of education—but certainly not in a research science department. Things have changed quite a bit since then; there are now numerous research physics departments with thriving physics education research programs. I believe that scientists are beginning to understand, and value, the contributions from the science of learning.

I am part of a group of 4 faculty members within a large research physics department. We have been well supported by federal grants for over 20 years. I also often collaborate with other cognitive scientists outside of physics, as well as with high school physics teachers. I have conducted learning studies with both high school and university students. Given my eclectic background, I believe that I have a broad perspective of the work, attitudes, and views of scientists, cognitive scientists, and teachers, and I will draw on that perspective in the testimony I will provide today.

Answers to Questions from the Subcommittee

1. *Where is the current state of knowledge on how people learn the strongest and in what areas do significant research gaps exist? Where are the biggest gaps between what we know about learning and what we know about teaching? What research programs should be undertaken to help close these gaps?*

We know a great deal about the nature of learning, and about how people learn effectively and eventually develop expertise. We know how experts learn information, store that information for effective retrieval from their memories, and how they solve problems. In particular, we know that skilled performance requires: 1) a store of knowledge, 2) knowledge that is understood and organized according to the major principles/laws/concepts of the area being studied, and 3) knowledge that is linked to contexts and situations in which learning can be applied and to procedures for applying learning (this facilitates the retrieval and application of knowledge). Building this highly refined knowledge network takes years, and this is one of the major reasons why most students find learning science difficult.

We also know a lot about the conditions under which previous learning can facilitate, or hinder, new learning. For example, we know that learners are not empty vessels into which knowledge can be poured in ready-to-use form. Learners bring knowledge from a lifetime of previous learning to any new learning situation, and if their previous knowledge (which is often incomplete, fragmented, and contains erroneous notions or misconceptions) conflicts with the new material being learned, it is highly likely that previous knowledge will interfere with the learning of new knowledge. We also know about a "rich-get-richer" principle of learning—the more you know about a topic, the easier it is to learn additional information about that topic.

Despite the vast knowledge base that has been developed in the science of learning, there are also significant gaps in our knowledge base, especially in an arena I will refer to as "learning that lasts" for both students and teachers. I now mention three areas in which more research is needed, and which have major ramifications for promoting "learning that lasts":

1) Knowledge transfer, that is, the flexible application of knowledge across life's different contexts and situations. At this point in time we know that transfer is very difficult to achieve, and very little is known about how one might structure teaching in ways that maximize transfer.
2) Facilitating the acquisition of "pedagogical content knowledge" for teachers. In the science of learning we use the term "pedagogical content knowledge" to mean knowledge of content (e.g., math, physics) that is inextricably linked to knowledge of effective pedagogical techniques for teaching that content. Effective models for structuring the educational experience for pre-service teachers, and the continuing education of in-service teachers, to promote and maximize the acquisition of "pedagogical content knowledge" remains a major challenge.

3) Assessment. We need ways of assessing a wider scope of students' knowledge than we are capable of with the assessments tools currently available. Therefore, more research and development is needed to develop and study two types of assessments: formative and summative. Formative assessments evaluate students' knowledge for purposes of improving instruction, and would allow teachers to tailor instruction to meet students needs. Summative assessments, which are intended to "sum up" students' knowledge, are needed to measure deep conceptual understanding and skilled problem solving behavior. Most current assessment instruments are summative in design and use, but they fall far short of effective evaluation of students' deep conceptual understanding.

Setting research priorities to focus on these three areas would have a major impact on improving teachers' teaching and students' learning.

2. *How should teacher training and certification programs be restructured so that elementary, middle and high school teachers are better prepared to teach science and mathematics?*

Current practices for the training of pre-service teachers, and for the continuing education of in-service teachers, are in need of major revision. The big problem for pre-service teacher training is the mismatch between the kind of teaching we would like pre-service teachers to adopt and the kind of teaching they experience in college science classes. Teaching should get learners actively engaged and the teacher should serve as a learning coach rather than a transmitter of information. But science content is taught by scientists using very traditional lecture methods, and pedagogy is taught by education faculty, with little to no communication or collaboration between these two groups. This practice is not conducive to helping teachers develop pedagogical content knowledge, and worse, it promotes a type of schizophrenia in prospective teachers—should they teach science the way scientists taught them or the way educators said they should teach? In short, the science of learning is not being mined enough in the education of pre-service teachers.

For in-service teachers, the issues differ somewhat. By the time teachers have been teaching science or math for a few years, they have formed a philosophy of teaching and have adopted concrete instructional practices. Teachers are not likely to change their philosophies or practices easily, even if those conflict with our best understanding of learning and teaching. Further, the workshop structure used commonly for the continuing education of in-service teachers is, by design, doomed to failure and does not follow the principles of learning that have been derived from the science of learning. In-service training practices are neither sustained, compelling, nor self-evident enough to change teaching practices in the short term and certainly will not impact teachers' deep knowledge of content or of pedagogy. I would sum this up by saying that it is time to develop a science of pedagogy based on the science of learning and to begin with an in-depth study of pre-service and in-service practices.

The question is how to restructure the pre-service and in-service educational experiences of teachers in the meantime so that they are better prepared to teach science and mathematics. Clearly this is a complex problem and there are no simple solutions or we would have found them by now. A good starting point is to examine teacher education reform through the lens of the science of learning. Learning research indicates that effective teaching requires that teachers possess three types of knowledge: 1) knowledge of content, 2) knowledge of the salient research findings pertaining to learning, and the implications of those findings to classroom practice, and 3) knowledge about instructional strategies to facilitate and monitor conceptual change and the development of problem solving skills. This combination is what I've been referring to as pedagogical content knowledge, and should be taught coherently rather than as isolated units. The image of weaving three types of strands into an integrated, detailed fabric comes to mind. To achieve this requires more cross-disciplinary collaboration among scientists, educators, teachers, and administrators. This suggestion is not unique: Today many of the exciting advances in science occur when scientists collaborate to blur the boundaries of their disciplines. For example, advances in nanotechnology are made by groups of physicists, polymer scientists, and chemists working together; advances in biotechnology requires pooled expertise from medicine, molecular biology, biochemistry and physics.

I would be remiss if I did not point out another major problem that directly affects the education of pre-service teachers, and which we could begin to address almost immediately, namely, the way we train our science Ph.D.s. The training of science Ph.D.s consists of immersing the candidate in science content, with no formal requirement demanding that the candidate learn something about learners' cognitive development or about pedagogy based on sound learning principles. Consequently, scientists know of no other way to teach than the way they were taught. Addressing this problem, for example by providing incentives to science departments to include courses on the science of learning and pedagogy, would go a long way in aligning the mismatch mentioned above and in curing, or at least alleviating, the schizophrenia we create in prospective teachers.

Although I haven't suggested a recipe for structuring teacher education and certification programs, I have suggested ingredients necessary for successful reform. Since universities are essentially entrepreneurial organizations, we need to provide incentives to both science departments and schools of education to reform science teaching and pedagogical training received by prospective teachers. For example, one way of achieving the type of collaboration needed among scientists, educators, teachers, and administrators in crafting new teacher training models is for agencies like NSF to offer program solicitations requiring such collaborations, and also requiring that any model proposed be based on sound principles of teaching and learning (e.g., as outlined in the National Research Council report, *How People Learn).* I am suggesting that the science of learning and the science of pedagogy need to be pursued as scientific research enterprises—searching for evidence that can improve our knowledge bases that will help address our nation's education problems.

3. *If we were to establish research centers linking education researchers with education practitioners for the purpose of developing and assessing best practices and materials, how should they be structured?*

I would like to begin my answer by addressing two phrases used in this question that carry some underlying assumptions. The first phrase, "linking education researchers with education practitioners," implies too narrow a collaboration. I would suggest that we need collaborations that include combinations of cognitive and disciplinary scientists, education researchers, education practitioners, and education administrators. The second phrase that I'd like to comment on is "best practices and materials." The problem here is that too often "best practices and materials" are based on accepted practices and folklore rather than on scientific evidence from the science of learning.

First and foremost, learning about learning involves studying human cognitive behavior, which is a very complex undertaking. If large research centers are to be funded to study the science of learning we need to fight the misconception that studying education, or fixing its problems, is easy simply because most of us went through the educational system and did well at it. To learn about, and solve the complex problems in education today, we need to draw on the expertise, and research methodologies, from various disciplines—for example, cognitive science, education, psychology, neuroscience, linguistics, the sciences, and anthropology, to name a few major ones. The types of collaborations I am suggesting will result in varied approaches to tackle varied problems. For example, studies will be designed that include: 1) Different methodologies (some qualitative some quantitative) from behavioral, cognitive, neural, and educational traditions, 2) Different time scales (some short term, some longitudinal), and 3) Different levels of analysis. To summarize, the need now is to generate new approaches to research complex human systems by studying human cognition and environmental factors that directly impact learning (e.g., home and school environments) using diverse methodologies across separate disciplines that comprise the cognitive, developmental, social, behavioral, and disciplinary sciences.

Finally, there is a structural assumption in the question above that may lead to undesirable outcomes. I would strongly argue that, in order to ensure that we continue building the science of learning research infrastructure so that we can make informed decisions about teaching practices and curriculum development, we not ignore the value of small grants to individual investigators. The trend I've seen at the National Science Foundation's Education and Human Resources directorate for some time now is to devote increasing resources to fund large projects requiring collaborations among a large number of individuals and institutions. Examples of these include the State, Urban, and Rural Systemic Initiative grants, the new Centers for Learning and Teaching, and the Interagency Education Research Initiative, to name a few. Although large projects have a place in science and math education reform, we are not devoting enough resources to fund "single investigator" grants (i.e., small collaborations between one or two scientists, post-doctoral associates, graduate students, and teachers).

Large project solicitations favor principal investigators who are good managers capable of putting together large teams of collaborators, but many excellent researchers, through no fault of their own, will never become part of these collaborations. We need to have the best science done by the best people, and this calls for also having more "open" competitions to attract the best research studies possible. Presently, there is only one program at NSF's EHR directorate that openly funds research on learning, and its resources are too meager to fund the kind of research infrastructure needed for science and math education reform. Programs are also needed to incorporate the scientific advances that are presently evident in the behavioral and cognitive sciences so that education can benefit from these knowledge bases. To neglect this need will mean we will likely soon outdistance our research knowledge base and be forced to make decisions about teaching and curriculum based on "art" rather than science. If we examine the large number of citations in the NRC's two recent reports on the science or learning, namely *How People Learn: Brain Mind, Experience and School*, and *How People Learn: Bridging Research and Practice*, we will find that the vast majority of the research cited came from funding the best people to do the best science. The field needs mechanisms to sustain and expand this excellent body of research and to not stifle it by devoting all new resources to large projects.

BIOGRAPHY FOR JOSE P. MESTRE

Education:

B.S., Physics, University of Massachusetts, 1974.
Ph.D., Physics, University of Massachusetts, 1979.

Positions Held:

1979–1981: Post-Doctoral Research Associate, UMass Amherst.
1982: Acting Director, Minority Engineering Program, UMass Amherst.
1981–1987: Visiting Assistant Professor of Physics, UMass Amherst.
1987–1993: Associate Professor of Physics, UMass Amherst.
1992–1993: Visiting Staff Associate, LRDC, U. of Pittsburgh.
1993-present: Professor of Physics, UMass Amherst.

Proposal / Manuscript Referee:

National Science Foundation, *The Physics Teacher, American Journal of Physics, Cognition and Instruction, Journal for Research in Mathematics Education, Journal of Educational Psychology, Contemporary Educational Psychology, Instructional Science, Journal of Computing in Higher Education.*

Professional Service:

Served on over 20 national advisory boards, panels, & committees.

Sample Service:

Present:

Technical Advisory Committee, Graduate Record Examination, Educational Testing Service, 1999-present.

National Task Force on Undergraduate Physics, American Physical Society, American Association of Physics Teachers, and American Institute of Physics, 1999-present.

Editorial Board of *The Journal of Physics Education Research,* 1997-present.

Past:

Member, *Committee on Developments in the Science of Learning* (1995–1998), and *Committee on Learning Research and Educational Practice* (1998–1999), Commission on Behavioral & Social Sciences & Education, National Research Council.

Chair, *Sciences Advisory Committee,* 1989–1992 (Member 1986–1992); Member, *Council on Academic Affairs,* 1989–1992; Member, *Scholastic Aptitude Test Committee,* 1987–1991, The College Board.

Research in Physics Education Committee, American Association of Physics Teachers, 1998–2000, and 1992–1995.

Member, *Advisory Panel—Project QUASAR,* Learning Research & Development Center, University of Pittsburgh, 1990–1997.

Member, *Mathematical Sciences Education Board,* National Academy of the Sciences/National Research Council, 1988–1991.

Member, *Visiting Committee,* Educational Testing Service, 1987–1990.

Member, *Standing Review Panel,* Applications for Advanced Technologies Program, National Science Foundation, 1988–1990.

Member, *Editorial Board* of *The Physics Teacher,* 1990–1993.

Member, *Expert Panel,* Federal Coordinating Council for Science, Engineering and Technology, Washington, D.C., 1992–1993.

Grants Summary: Thirteen grants totaling over $4,000,000.

Publication-Presentation Summary: 90 Talks/Workshops/Invited Presentations & Conferences; 57 Articles and 15 Books Published.

Selected Publications:

Mestre, J.P. & Touger, J.S. (1989). Cognitive research: What's in it for physics teachers? *The Physics Teacher,* 27, 447–456.

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Royer, J.M., Carlo, M.S., Dufresne, R., & Mestre, J. (1996). The assessment of levels of domain expertise while reading. *Cognition & Instruction,* 14, 373–408.

Mestre, J.P. (2000). Progress in research: The interplay among theory, research questions, and measurement techniques. In R. Lesh, R. & A. Kelly, (Eds.), *Handbook of research methodologies for science and mathematics education* (pp. 151–168).

Mahwah, NJ: LEA. Mestre, J.P. (2001). Implications of research on learning for the education of prospective science and physics teachers. *Physics Education,* 36, #1, 44–51.

Mestre, J.P. (accepted for publication). Probing conceptual understanding and transfer in physics via problem posing. *Journal of Applied Developmental Psychology.*

Books:

Cocking, R.R. & Mestre, J.P. (Eds.) (1988). *Linguistic and Cultural Influences on Learning Mathematics,* Hillsdale, NJ: Lawrence Erlbaum Associates.

Mestre, J.P. & Lochhead, J. (1990). *Academic Preparation in Science: Teaching for Transition from High School to College*—Second Edition. New York, NY: The College Board.

Leonard, W., Dufresne, R., Gerace, W., & Mestre, J. (1999). *Minds-On Physics.* Dubuque, IA: Kendall/Hunt Publishing. (6 student books and 6 teacher guides.)

Mestre, J.P. & Cocking, R.R. (Eds.) (2000). Special Issue on the Science of Learning, *Journal of Applied Developmental Psychology,* 21, #1 (Jan.-Feb.).

UNIVERSITY of
MASSACHUSETTS
1126 Lederle Graduate Research Center Towers
Box 34525
Amherst, MA 01003-4525
UMASS

Department of Physics

voice: 413.545.2545
fax: 413.545.0648

May 8, 2001

The Honorable Sherwood L. Boehlert, Chairman
Committee on Science
U.S. House of Representatives
B-374 Rayburn Building
Washington, D.C. 20515

Dear Chairman Boehlert:

According to the rules governing testimony for the Committee on Science, I am required to reveal my sources of Federal Government funding. I currently have two sources of funding. The first is a grant from the Education and Human Resources directorate of the National Science Foundation (grant #ESI-9730438) titled "Assessing to Learn: Formative Assessment Materials for High School Physics." The second is a subcontract, titled "Evaluation of Operation Primary Physical Science Project," from a grant to Louisiana State University from the National Science Foundation's Education and Human Resource directorate.

Sincerely,

Jose P. Mestre

Jose P. Mestre
Professor of Physics

Chairman SMITH. Thank you. Dr. Songer.

STATEMENT OF DR. NANCY B. SONGER, PROFESSOR OF EDUCATION, UNIVERSITY OF MICHIGAN

Dr. SONGER. Despite the demands for a scientifically and technologically literate public, the challenge to provide quality K–12 science education appears particularly pronounced. Research demonstrates that between fourth and eight grade, American students' achievement and understanding of complex science decline relative to their peers internationally. For urban students, these declines are even more dramatic, and in many inner-city classrooms, the threat of failure fuels enormous pressure to perform well on high-stakes tests causing an unnatural emphasis on teaching to the test and other practices which research demonstrates do not result in long-term learning.

From my viewpoint, this crisis is particularly interesting because I believe my colleagues and I know a great deal about how to foster the learning of complex science and other high-order thinking skills, yet our research results are not having much direct impact in today's classrooms.

What can be done to facilitate greater impact of learning research on the practices in today's classrooms? I suggest four necessary, but perhaps not sufficient, steps toward realizing this goal.

First, we need very specific kinds of long-term partnerships in order to implement the challenging agenda. We need more government-funded national research centers with particular focus on realizing the impact of learning research in today's educational systems, from kindergarten through college undergraduates. These centers must be guided by a leadership structure that is managed by university educational researchers, yet has district superintendents and discipline specialists, such as chemists, biologists, and software engineers, as essential co-leaders.

The inclusion of university-based content specialists would both ensure quality content in the K–12 program, as well as advance the understanding of strong pedagogy at the university level, thereby allowing greater direct impact of learning research on both K–12 and university-level teaching.

The Center for Learning Technologies in Urban Schools, a center I am affiliated with that is funded by the NSF, is one exemplary case of this model. We have directors that include two superintendents, one each from Chicago and Detroit Public Schools, as well as university researchers from Northwestern and Michigan. In general, my work suggests that without an infrastructure, including partnership research centers with specific co-leadership within and outside the school districts, the learning theories cannot be appropriately translated into tangible products for schools.

Second, we need a much higher number of educational programs that are created based on learning research as applied to classroom settings. In terms of the learning fostered, these programs would, for example, help children of poverty in urban Detroit investigate scientific questions focusing on relevant and important scientific events. Rather than encouraging children to memorize facts about weather or animals, learning-driven programs guide children to work alongside National Hurricane Center scientists in the prediction of a live hurricane off the coast of Florida, or in the interpretation of species diversity data they have collected in their city using Palm Pilots and the software of professional African animal trackers.

The National Science Foundation supports the development and research on many quality programs of this kind, however, very few of these are reaching large-scale impact.

Third, large-scale impact requires long-term commitment from school administrators, educational researchers, and teachers. The Interagency Education Research Initiative, IERI, is one example of a multi-agency initiative that provides several of the necessary ingredients toward the development of sustained relationships, research agendas, and research-driven classroom impact. Our current work funded under IERI holds more promise for impact in part because of the 5 years of large-scale funding, which allows us to build and support several dimensions of the necessary infrastructure, including long-term relationships with teachers, a 4-year coordinated curricula, and a longitudinal research agenda tracking ten cohorts of students for 4 years each.

Each run of our program, we implement the same program with about 10,000 children in 250 classrooms coordinated across the United States. With some variation, all of our teachers hold the same larger learning goal, which is that learning involves collecting and analyzing data, formulating questions about evidence, generating explanations from evidence, and connecting evidence to scientific knowledge.

My fourth point is that we need learning-based programs that work for a wide range of children. And in order to do this, we need dissemination models that respect both high common standards based on learning research and variations that allow adjustments for particular classroom contexts and populations.

Recently, I discovered that a Detroit middle school class of 36 students was not able to participate in our science program because there were only 17 chairs in the large closet-like room used for the computer lab. As this simple example illustrates, my colleagues and I know a great deal more about fostering learning in science than is being realized into today's schools. As we embrace a global economy in a technological world, all of our children, not just those in more affluent schools and neighborhoods, need thinking skills and literacies to participate as productive, informed citizens.

Even with the strong funding and research history we have been fortunate to achieve in the current system, these understandings will remain anecdotal and of small impact nationally without systemic changes in the infrastructure and models of dissemination needed to organize, translate, and implement them on a much larger scale.

[The prepared statement of Dr. Songer follows:]

PREPARED STATEMENT OF NANCY B. SONGER

Parents, educators, politicians, and the general public agree that the crisis in American education is severe. Despite the demands for a scientifically and technologically literate public, the challenge to provide quality K–12 science education appears particularly pronounced. Research demonstrates that between fourth and eighth grade, American students' achievement and understandings of complex science decline relative to their peers internationally (Linn, Lewis, Tsuchida and

Songer, 2000). For urban students these declines are even more dramatic and, in many inner-city classrooms, the threat of failure fuels enormous pressure to perform well on high-stakes tests causing an unnatural emphasis on "teaching to the test" and other practices which research demonstrates do not result in long-term learning. As a teacher in a failing South Bronx school recently documented, the mantras necessary to be a successful urban teacher have little to do with teaching and learning, but instead consist of "cover yourself" and "don't' ask, don't tell" (Kingon, 2001).

From my viewpoint, this crisis is particularly interesting because I believe my colleagues and I know a great deal about how to foster the learning of complex science and other higher-order thinking skills, yet our research results are not having much direct impact in today's classrooms. Researchers in reading education have made good progress impacting classroom practice, and, in general, have outperformed science and mathematics educators in realizing classroom impact from research results. The comments from a Michigan 6th grade teacher I interviewed this week summarize the current thinking of many when she stated, "even kids that can solve math problems or remember science facts have a difficult time thinking scientifically or thinking conceptually about math. They have math and science beliefs, but they really can't substantiate why they believe what they do."

What can be done to facilitate greater impact of learning research on the practices in today's classrooms? I suggest four necessary, but perhaps not sufficient, steps towards realizing large-scale impact of educational research in America's classrooms.

1. Partnership Research Centers

We need very specific kinds of long-term partnerships in order to implement this challenging agenda. First, we need more government-funded national research centers with particular focus on realizing the impact of learning research in today's educational systems, from kindergarten through college undergraduates. These centers must be guided by a leadership structure that is managed by university educational researchers, yet has district superintendents as essential co-leaders and Co-PIs. In addition, the leadership team must include discipline specialists such as chemists, biologists, mathematicians and software engineers. The inclusion of content specialists would both ensure quality content and technological resources in the K–12 programs, as well as advance the understanding of strong pedagogy at the university level thereby allowing greater direct impact of learning research on both K–12 and university-level teaching. Leadership by educational researchers is also essential in that it ensures that a quality research agenda will lead the iterative improvements and implementation, allowing us to best learn from and understand our learning outcomes, barriers, and the evolution of new ideas.

The Center for Learning Technologies in Urban Schools (LeTUS), a center I am affiliated with that is funded by the National Science Foundation, is one exemplary case of this model. Center directors include two superintendents, one each from both the Chicago and Detroit Public Schools, as well as two university researchers, one each from the partner universities of The University of Michigan and Northwestern University. Center work focuses on the direct translation of learning research into the development of tangible programs, models of professional development, and student outcomes. While this example specifically addresses impact within urban schools, different manifestations of this model might emphasize different foci and might not necessarily remain focused on a particular geographic region.

In general, my work suggests that without an infrastructure including partnership research centers with specific co-leadership both within and outside the school districts, the learning theories can not be appropriately translated into tangible products for schools.

2. Congruence between Testing, Pedagogy, and Curricula Towards Impact

We need a much higher number of educational programs that are created based on learning research as applied to classroom settings. These programs, while manifestations of what we know about how children learn, would also strive to align with state and district curricular frameworks and high-stakes tests so as to be usable by schools that are working within these guidelines.

In terms of the learning fostered, these programs would, for example, help children of poverty in urban Detroit investigate scientific questions focusing on relevant and important scientific events. Rather than encouraging children to memorize facts about weather or animals, learning-driven programs guide children to work alongside National Hurricane Center scientists in the prediction of a live hurricane off the coast of Florida, or in the interpretation of species diversity data they have collected in their city using Palm Pilots and the software of professional African animal trackers.

The National Science Foundation supports the development and research on many quality programs of this kind in science and mathematics. However, very few of these reach large-scale impact. While my colleagues and I represent a handful of such boutique programs, my program, titled *Kids as Global Scientists*, currently, I believe, has the largest impact of these in schools, and we have worked with only 46,000 middle school children in the past three years. Once programs such as ours have proven successful in many schools, we need much stronger mechanisms for helping these programs to become available and supported on a wide scale, so that they can impact millions of learners rather than thousands.

3. Longevity of Working Relationships, Reforms and Research

Large-scale impact requires long-term commitment from school administrators, educational researchers, and teachers. Implementing this change would require a reexamination of most current funding cycles, which provide funding for only three years at a time, a formula that disallows much opportunity to build long-term relationships or sustaining programs and research agendas.

The Interagency Education Research Initiative (IERI) is one example of a multi-agency initiative that provides several of the necessary ingredients towards the development of sustained relationships, research agendas, and research-driven classroom impact. IERI was developed to provide concrete examples of the impact of learning-focused research on the practice within schools. Developed by an inter-agency team consisting of the National Science Foundation (NSF), the Department of Education's Office of Educational Research and Improvement (OERI), and the National Institute of Child Health and Human Development (NICHD), IERI serves as an important model of the kinds of funding structures needed for the challenges ahead. Our current work funded under IERI holds more promise for impact in part because of our five years of large-scale funding which allows us to build and support several dimensions of the necessary infrastructure including relationships with teachers, a four-year coordinated curricula, and a longitudinal research agenda tracking ten cohorts of students for four years each.

Why is longevity important? Our research demonstrates that while most our teachers notice gains in student beliefs and understandings of science after utilizing our programs one or two years, our teachers state that they do not feel completely comfortable guiding scientific thinking until about the *third year* of implementing our programs. This is consistent with much of educational research, such as results that document that a change in teachers' beliefs precedes a change in teachers' practice. Learning research also advocates curricula programs with more time on fewer concepts so that understandings such as fostering complex scientific thinking can develop. Our program utilizes a mull-year, coordinated curricular sequence in science that supports childrens' revisiting of scientific thinking skills such as building explanations from evidence each year with increasing complexity. Similarly, the research program tracking the developing of complex thinking in science should follow students for several years through these mull-year, coordinated programs.

4. Digital Library of Working Exemplars or Other Centralized Systems of Dissemination That Encourage Classroom-Level Customizations of Similar Goals

Each run, we implement the "same" program with about 10,000 children simultaneously in about 250 classrooms coordinated across the United States. While I have not personally visited each of these classrooms, I believe I can say with confidence that each teacher implements our program in an unique way, depending on the age, learning style, level of homogeneity, type of community, state testing structure, and district and school constraints placed on that individual and classroom. Interestingly, I believe all of our teachers hold the same larger goal as we do which is to help their children learn to think scientifically about weather or biodiversity. I think we all also agree, with some slight variations, that "learning scientifically" involves a kind of thinking far beyond reading middle school science textbooks or the memorization of animal facts and includes: collecting and analyzing data, formulating questions about their evidence, generating explanations from evidence, and connecting evidence to scientific knowledge through real-time predictions.

Recognizing the need for quality, learning-based programs that "work" for a wide range of children, we need dissemination models that respect both high common standards based on learning research, and variations that allows adjustments for particularly classroom contexts and populations. As one example, while we wish all children to improve their ability to thinking critically in science, research on learning in urban classrooms helps us understand that the professional development program needed to specifically challenge "the pedagogy of poverty" common in urban classrooms is different in important ways from the professional development program needed to foster learning within another focus population. Research also helps us understand that teachers need buy-in, and an important way to ensure this is to demonstrate the manner in which a particular program has been adapted towards the specifics of their context and learners.

One manifestation of this dissemination model that several of my colleagues are working towards is the development of a systematic digital library of working exemplars. Other countries, such as Japan, provide centralized systems for life-long teacher professional development consistent with current research findings. We need, at a minimum, a digital library of video clips, lesson plans, facilitated Internet discussions and other resources that begin to articulate and exemplify classroom manifestations of current research ideas. An even stronger version of this idea would involve the systematic development of online courses, offered through centers such as the LeTUS center mentioned above, for in-service and pre-service teachers' ongoing discussion of pedagogical practices current with educational research.

Summary

Recently, I discovered that a Detroit middle school class of 36 students was not able to participate in our science program because there were only 17 chairs in the large closet-like room used for the computer lab. As this simple example illustrates, my colleagues and I know a great deal more about fostering learning in science than is being realized in today's schools. As we embrace a global economy and a technological world, all of our children, not just those in more affluent schools and neighborhoods, need thinking skills and technological fluency to participate as productive, informed citizens. Educational programs such as ours that develop and research best means for the development of these literacies, as well as foster them early, often, and systematically over time, contribute to the understandings we need to support all our children in their quest to embrace their future and succeed. But even with the strong funding and research history we have been fortunate to achieve in the current system, these understandings will remain anecdotal and of small impact nationally without systemic changes in the infrastructure and models of dissemination needed to organize, translate, and implement them on a much larger scale.

Linn, M.C., Tsuchida, L., Lewis, C. and Songer, N.B. (2000) Beyond Fourth Grade Science: Why do US and Japanese students diverge? *Educational Researcher* 29(4), 4–14.

Kingon, J.G. (2001) A View From the Trenches. *The New York Times*. Education Life Supplement. Also available at: http://www.nytimes.com/2001/04/08/education/08ED-KING.html?pagewanted=all.

Biography for Nancy Butler Songer

Business Address:

University of Michigan, School of Education, 610 E. University Ave., 1323 SEB, Ann Arbor, MI 48109; songern@umich.edu; phone: (734) 647–7369; FAX: (734) 763–1368

Research Expertise

The impact of emerging technologies on students' understandings, intellectual development, and motivation to learn, particularly the learning of science, and specifically urban students and/or students in schools with impoverished conditions. Principles of the design of technology-enhanced learning environments.

Current Research

Characterizing urban children's longitudinal understandings of higher-order thinking in science throughout four years of intensive technology-rich science immersion. Systemic confrontation to the barriers that constitute "the pedagogy of poverty."

Education

Ph.D., 1989—Science Education, University of California, Berkeley, CA.
M.S., 1984—Molecular/Developmental Biology, Tufts University, Medford, MA.
B.S., 1981—Biological Sciences, University of California, Davis, CA.

Recent Professional Experience

1996-present Associate Professor of Science Education & Educational Technology, School of Education, University of Michigan, Ann Arbor
1991–1996 Assistant Professor of Science Education, School of Education, University of Colorado, Boulder
1989–1990 Post-Doctoral Scholar, University of California, Berkeley
1987, 1981–1985 Research Technician II, Molecular Biology.

Selected Honors, Awards

- U.S. Department of Education, Promising Educational Technology Award 2000
- 2000 Computerworld Smithsonian Laureate and Exhibitor
- National Science Foundation Presidential Faculty Fellow 1995.
- Early Career Research Award, Natl Assoc. of Research in Science Teaching (NARST) 1995
- University of California Regents Graduate Fellow 1987–1988
- Outstanding Graduate Student Instructor, University of California, Berkeley 1985–1986

Advisory Groups

- The National Research Council (scientific principles in ed. research; tech literacy)
- The U.S. Department of Education (OERI Committee on Educational Technology)
- NASA Classroom of the Future
- The Kellogg Foundation
- Project GLOBE (early design of educational programs)
- National Education Summit 1999

Selected Funded Grants and Contracts

2001–2005 BioKIDS: Kids' Inquiry of Diverse Species. Interagency Education Research Initiative (IERI), ($4,564,681)
1998–2001 Researching Scaling and Accountability of On-Line Science Curriculum for Maverick and Distributed Populations. National Science Foundation/REPP ($1.1 million)
1996–2000 National Science Foundation, Presidential Faculty Fellow. 500K
1995–1998 Application of Computer Technology to Promote Collaborative Research Communities in K–12 Education, NSF/NIE. ($2.3 million)
1992–1996 Kids as Global Scientists: The Utilization of the Internet for Middle School Atmospheric Science, NSF/AAT. ($242,360)
1994–1995 The Weather Underground: Application of Computer Technology to Science in Michigan Secondary Schools, NSF ($25,000)
1995–1998 Enhancing Children's Understanding of Science Through Collaborative Creation of Animated Models, NSF ($1 million)
1995–1998 Innovation in Elementary Science:Two Cases from Japan NSF (600K)

1991–1992 Literary in the Service of Action in Grades 6–8, Mellon Foundation ($200,000)

Selected Recent Publications

Songer, N.B., Lee, H.S. and Kam, R. (in press). Technology-Rich Inquiry Science in Urban Classrooms: What are the barriers to inquiry pedagogy? *Journal of Research in Science Teaching.*

Linn, M.C., Tsuchida, I., Lewis, C. and Songer, N.B. (2000) Beyond Fourth Grade Science: Why do US and Japanese students diverge? *Educational Researcher.*

Songer, N.B., Lee, S.Y. (2000) The Social Context Surrounding Learning with Visualization Tools. On-line publication, www.cilt.org

Songer, N.B. (2000) Scaling Beyond Mavericks: What Do Our Experiences Tell Us? Online publication, www.cilt.org

Mistler-Jackson, M. and Songer, N.B. (2000) Student Motivation and Internet Technology: Are students empowered to learn science? *Journal of Research in Science Teaching.*

Songer, N.B. (1998) Can Technology Bring Students Closer to Science? in K. Tobin and B. Fraser (Eds.) *The International Handbook of Science Education,* The Netherlands: Kluwer. pp. 333–348.

Songer, N.B. (1998) Kids as Global Scientists, in T. Owen and R. Owston (Eds.) *The Learning Highway: Smart Students and the Net* (A winner of the New York Public Library's Books for the Teen Age Award). Toronto: Key Porter Books.

Linn, M.C., Songer, N.B., and Eylon, B. (1996) Chapter 15: Shifts and convergences in science learning and instruction, in D. Berliner and R. Calfee (Eds.) *The Handbook of Educational Psychology.* New York: Macmillan.

Songer, N.B. (1996) Exploring Learning Opportunities in Coordinated Network-Enhanced Classrooms: A case of kids as global scientists. *The Journal of the Learning Sciences* 5(4), 297–327.

THE UNIVERSITY OF MICHIGAN
SCHOOL OF EDUCATION

EDUCATIONAL STUDIES PROGRAM
610 E. UNIVERSITY, 1225 SEB
ANN ARBOR, MICHIGAN 48109-1259
734-763-9497 FAX: 734-763-1229

The Honorable Chairman Boehlert, Chair
U.S. House of Representatives
Committee on Science
Research Subcommittee
B-374 Rayburn Building
Washington, D.C. 20515

Tuesday, May 8, 2001

Dear Chairman Boehlert,

Noted below are the federal government grants, awarded under my direction, that directly support the subject matter I will be addressing at the May 10th hearing:

2001-2005	BioKIDS: Kids' Inquiry of Diverse Species. Interagency Education Research Initiative (IERI), ($4,564,681)
1998-2001	Researching Scaling and Accountability of On-Line Science Curriculum for Maverick and Distributed Populations. National Science Foundation/REPP ($1.1 million)
1996-2000	National Science Foundation, Presidential Faculty Fellow. ($500,000.)
1995-1998	Application of Computer Technology to Promote Collaborative Research Communities in K-12 Education, NSF/NIE. ($2.3 million)
1992-1996	Kids as Global Scientists: The Utilization of the Internet for Middle School Atmospheric Science, NSF/AAT. ($242, 360.)
1994-1995	The Weather Underground: Application of Computer Technology to Science in Michigan Secondary Schools. NSF ($25,000.)
1995-1998	Innovation in Elementary Science: Two Cases from Japan NSF 600K

Please let me know if you have additional questions.

Sincerely,

Nancy Songer

Dr. Nancy Butler Songer
Associate Professor, Science Education & Ed Tech
Director, The One Sky, Many Voices/ BioKIDS Projects
610 East University Ave.
1323 School of Education Building
The University of Michigan
Ann Arbor, MI. 48109-1259

STATEMENT OF DR. CHRIS DEDE, TIMOTHY E. WIRTH PROFESSOR OF LEARNING TECHNOLOGIES, HARVARD UNIVERSITY

Dr. DEDE. I am going to describe learning technologies research, but that is as a stalking horse for almost any kind of educational research intervention. One sort of critical lack of knowledge deals with the conditions for success under which a promising research initiative can actually be implemented in the real world.

I want you to image somebody dropping a vial of antibiotics into a stone-age culture without any instructions about how to use them. Some people would worship the vial of antibiotics. Some people would grind them up and smear them all over their bodies. Some people would take all the antibiotics at once. Probably relatively few would figure out to take one every 4 hours or so. Now, here is a powerful technology, but it is a technology that only works if it is used under a particular set of conditions for success. And typically, interventions in educations, technological or not, have complex conditions for success. They are not like immunizations, where once you just get the immunization you are covered. They are far more complex than antibiotics or most of the other kinds of public health interventions that we look at.

Now, American business in the 1980's faced a similar sort of situation with information technology. People were implementing computers, they were doing data processing of different kinds, and the productivity gains were not happening. There were articles appearing in business journals, at that time, wondering whether this whole emphasis on information technology was a huge mistake. But because business persisted and sorted out the conditions for success and made the kinds of organizational changes that were required for those technologies to be powerful, we now have some of the economic prosperity that we have seen over the last decade.

And we are at a comparable kind of situation in education now. It is not a matter of the technology is not being powerful. It is a matter of understanding how the organizations must change to create the conditions for success. And research on that is extremely important and it can't be conducted in the laboratory settings. It has to be conducted in real-world implementations.

Now, there are some good precursor models of how the government can do this. There are funding programs that my colleagues have cited, that are part of the charge to the Committee, that are promising. In terms of those approaches, there are centers that the NSF has funded, such as the Center for Learning Technologies in Urban Schools, that Nancy was describing, that have walked down this path. There are proposals about research agendas that have been made that bring this in. And in my written testimony, I talk about those issues.

I want to make five recommendations on creating centers of that type. The first is, that the centers really need to be problem-focused. It would be a mistake to have a center, say, on neurosciences in education or cognitive sciences in education, not because that isn't an important topic, but because that leads it in a basic research direction. If we say that we want a center on the diagnostic student assessment, that takes something that every teacher wrestles with every day and focuses neuroscience, cognitive science, a wide variety of basic research areas, on that problem. So making them problem-focused is very important.

The second is that the centers need to be adequately funded. These are not problems that are going to be solved in 2 months or 2 years. It is going to take time. It is going to take scale. And it is going to take a level of focus on educational research that we haven't historically seen.

The third is that the centers really need to build capacity. Right now, if a huge amount of money were thrown into educational research of this type, there would not be a sufficient body of researchers trained to do it well to accomplish these goals. Often, the kinds of research training that people receive are very much toward basic research, rather than this kind of use-driven basic research. And capacity-building needs to be part of the design of the centers so that a whole generation of young researchers can come up capable of doing this kind of work.

The fourth recommendation is that these not be done through directed appropriations. These are centers that should be competitively awarded based on the quality of the ideas presented.

And the fifth is that this is not the kind of initiative that can be done through decentralizing into the states and using a block grant mechanism. These are centers that need to be at the Federal level, because only at the Federal level can the kind of concentration of resources and the community of mind take place to make these centers happen.

Finally, if everything that I have said has been done, there still is a more fundamental problem that is a context within which this initiative is being considered, and that is a problem with a misguided reform strategy that is now taking place in education.

I want you to imagine the problem a public health official might face if there was a mandate given to the American people that every person had to eat 5,000 calories a day. And so here we are, all of us are stuffing in, getting in our 5,000 calories, and then someone comes along and says, well, why are you eating so many fats? Why aren't you eating more fruits and vegetables? Well, I have got to get my 5,000 calories a day, and fats are the quickest way to do it. Well, why aren't you exercising more? We know exercise is good for you. Well, it is hard for me to find time for exercise. I have got to spend all this time eating.

Well, we are giving our teachers 27 years' worth of content in the curriculum standards to teach in a 12-year period. We are telling them to teach higher-order skills and yet we are using low-level testing mechanisms. And then we are saying, well, why aren't you paying attention to research? The research centers will only work if there are also more fundamental changes in how we think about reform. Thank you very much.

[The prepared statement of Dr. Dede follows:]

PREPARED STATEMENT OF CHRIS DEDE

Creating Research Centers to Enhance the Effective Use of Learning Technologies

Emerging information technologies, such as the Web, are reshaping education in several ways. As sophisticated computers and telecommunications alter the nature of work and citizenship, the skills and concepts students must attain to be productive adults in 21st century society are changing. Also, in ways not possible until now, pupils and teachers can use new interactive media to enhance their learning in school and out. Further, researchers and educators who foster the dissemination of best practices can utilize information technology to form virtual communities of practice that empower reforms in schooling. Overall, rapidly evolving information devices, tools, media, and infrastructures are transforming what we learn, how we acquire this knowledge, and the processes by which we evolve our educational institutions.

This analysis focuses on how federal initiatives in funding educational research could advance the effective use of learning technologies to improve students' educational outcomes and the organization of schooling. Educational research is vital to ensure that school reform initiatives are reflective, ongoing processes of continuing improvement rather than occasional spasms of discontinuous and unsustainable change. Federal funding both for research centers and for competitive grants to individual projects is essential to provide a diverse "ecology of innovation" from which the best strategies for educational improvement emerge.

This testimony first analyzes what we know about the effective use of learning technologies; their importance in preparing students for the 21st century knowledge based economy; the rapid evolution of these devices, tools, and media; and issues in evaluating the effectiveness of learning technologies. Then, answers to three questions are provided:

- *How can policy makers help prepare schools and teachers to use learning technologies effectively in classroom instruction and student assessment?*
- *Would standards for and evaluations of technology-based learning experiences help teachers find high quality curriculum materials?*
- *Could well-structured research centers linking scholars with education practitioners develop and evaluate effective technology-based learning experiences?*

The testimony concludes with recommendations for federal policy initiatives to increase the effective development and implementation of learning technologies.

What We Know about the Effective Use of Learning Technologies

Sophisticated computers and telecommunications, including the Web, are reshaping the mission, objectives, content, and processes of U.S. schooling (Dede, 2000). This is part of a larger shift in our society from a 20th century mature national industrial economy to a 21st century interconnected, knowledge-based global marketplace (Dertouzos & Gates, 1998). Driven by advances in information technology, this economic evolution is the most radical change in American society since the dawn of the industrial revolution (Thurow, 1999). In response, all types of societal institutions are altering—even schools and colleges. Since one of education's goals is to prepare students for work and citizenship, schools, universities, States, and the federal government are all attempting to change their policies and practices to prepare pupils and teachers for an uncertain future context quite different than the immediate past (Tucker & Codding, 1998).

The issue is not simply aiding more students to reach a higher standard of achievement in today's curriculum (e.g., having all pupils take algebra rather than some, or raising everyone's scores on high-stakes tests to passing levels). While these goals are desirable, such improvements in traditional educational outcomes axe inadequate to prepare pupils for 21st century civilization (Dede, 1998a). All students also need to master higher-order cognitive, affective, and social skills not central to mature industrial societies, but vital in a knowledge based economy (Drucker, 1994). These include 'thriving on chaos' (making rapid decisions based on incomplete information to resolve novel situations); the ability to collaborate with a diverse team—face-to-face or across distance—to accomplish a task; and creating, sharing, and mastering knowledge through filtering a sea of quasi-accurate information (Peters, 1997). To raise all students to these advanced levels of accomplishment requires the sophisticated use of technology to individualize learning.

This means that the school curriculum must contain excellent, effective learning experiences that foster the development of this sophisticated knowledge. Also, teachers both must have these higher-order skills and must inculcate them in students. These capabilities for knowledge creation, sharing, and mastery go beyond the technical literacy many States are now requiring for teachers in preparation and in practice. Skills such as using databases, designing web pages, and troubleshooting hardware problems are useful for educators and should be part of teacher preparation and professional development. However, these technical capabilities are most valuable when fostered in the context of helping educators making rapid decisions based on incomplete information to resolve novel situations, collaborate, and filter quasi-accurate information in their professional work. This ensures that information technology is mastered as a means to an end (e.g., communal knowledge-based decision making) rather than as an end in itself. When pupils learn from a teacher with these higher order capabilities, using a curriculum based on developing 21st century skills and knowledge, students not only master technology literacy skills, but also successfully apply these to complex, authentic projects that involve knowledge creation, sharing, and mastery.

How Learning Technologies Can Prepare Students for the 21st Century

Just as information technology has improved effectiveness and efficiency in medicine, finance, manufacturing, and numerous other sectors of society, advanced computing and telecommunications have the potential to help all students. and teachers learn complex concepts and skills (President's Committee of Advisors in Science and Technology, 1997). Emerging interactive media reach their full potential in service of richer curricula, enhanced pedagogies, more effective organizational structures, stronger links between schools and society, and the empowerment of disenfranchised learners (Trotter, 1998). However, learning technologies are worth the time, effort, and resources required for widespread implementation only when they are used appropriately. Technology is not a 'vitamin' whose mere presence in schools and teacher preparation programs catalyzes better educational outcomes.

Sophisticated computers and telecommunications have unique capabilities for enhancing learning (Dede, 2000). These include:

- Enabling the learning of advanced content by a broader range of students earlier in their developmental progression (Horwitz, 1999; Roschelle, Kaput, & Stroup, 2000).
- centering the curriculum on 'authentic' problems parallel to those adults face in real-world settings (Cognition and Technology Group at Vanderbilt, 1997)
- involving students in virtual communities-of-practice, using advanced tools similar to those in today's high-tech workplaces (Line, 1997)
- facilitating guided, reflective inquiry through extended projects that inculcate sophisticated concepts and skills and generate complex products (Schank, Fano, Bell, & Jona, 1994).
- utilizing modeling and visualization as powerful means of bridging between experience and abstraction (Gordin & Pea, 1995)
- enhancing students' collaborative construction of meaning via different perspectives on shared experiences (Char, Burtis, & Bereiter, 1997)
- including pupils as partners in developing learning experiences and generating knowledge (Scardamalia & Bereiter, 1994)
- fostering success for all students through special measures to aid the disabled and the disenfranchised (Behrmann, 1998)

However, realizing these capabilities requires a complex implementation process that includes sustained, large-scale, simultaneous innovations in curriculum; pedagogy; assessment; professional development; administration; organizational structures; strategies for equity; and partnerships for learning among schools, businesses, homes, and community (Dede, 1998b).

Learning experiences that use the full capabilities of today's computers and telecommunications have a number of common characteristics. Students and teachers engage in guided, reflective inquiry through extended projects that generate complex products and inculcate sophisticated concepts and skills. Pupils act as partners in developing learning experiences and generating knowledge. Through interactions both inside the classroom and with distant archives and experts, their collaborative construction of meaning is enhanced via different perspectives on shared experiences.

These points can be illustrated by briefly describing an exemplary technology-based learning experience developed through the University of Michigan's Center for Highly-Interactive Computing in Education. A curriculum, ScienceWare, supports students as they investigate water quality issues in their community and link those data to national scientific investigations (Jackson, Stratford, Krajcik, & Soloway 1996). ScienceWare has tools that support all phases of students' investigations: data gathering (RiverBank); data visualization (Viz-It); modeling (Model-It); project planning for students (PlanIt-Out); publishing findings on the Internet (Web-It); and project planning for teachers (PIViT). Of these, the Model-It tool best illustrates the unique contributions information technology can make to learning and the ways a well designed application can generalize across a wide variety of curricular subjects.

Figure 1 depicts the World View, one of the two main representations provided by Model-It. *[All figures are presented in the Appendix to this testimony.]* In this example, the World View's background is an actual photo of Traver Creek, a stream behind a high school in Ann Arbor, Michigan at which a 9th grade science class explored the creek's water quality. The icons at the bottom of the window are objects that can be inserted into the World View (e.g., 'weather', a 'people' icon representing humans fertilizing the park that borders on the stream). When it rains, fertilizer from. the park gets washed into the stream, changing its levels of nitrates, dissolved oxygen, water quality, etc. Figure 1 also illustrates what students see as they run their model. Meters and graphs provide rich visualizations of the dynamics of the model. In addition, an independent variable's meter (in this case the Weather Rainfall factor) can be used to change the simulation during run-time.

To construct a model, students must create 1) *objects* ("things" in the model, such as insects, streams, people); 2) *factors* (variables related to the objects created); and 3) *relationships* among objects' factors. In the Relationship Editor window, students build a relationship by constructing a sentence via selecting words from drop-down menus. For example, in figure 2 a student is building a relationship between the nitrates (a factor) in the stream (an object) and the stream's water quality (a factor): 'As Stream: Nitrates increase, the Stream: Water Quality increases, by more and more.' Notice that the graph on the right-hand side is linked to the text expression, altering in response to any changes in the sentence. The graph can help students to bridge qualitative and quantitative representations; Model-It's underlying computational architecture uses differential equations to actualize students' qualitative, textually expressed relationships.

In a detailed study, Stratford, Krajcik, and Soloway (1997) analyzed final models from 50 students, as well as videotaped conversations and interviews with 8 pairs of those students as they built models of stream ecology. Fully 75% of the models analyzed were scientifically meaningful. Students created models that were coherent, accurate and well behaved; their models made sense and were non-trivial. For example, figure 3 shows a model created by 2 ninth grade students. These models indicated that the students knew what they were doing and were able to express what they knew about stream ecosystem phenomena in the form of a dynamic model.

Modeling is an important skill that underlies many topics in the curriculum beyond science and mathematics. For example, social scientists, historians, and economists use models to understand dynamic changes in their fields' phenomena. While the rules underlying these models may not be as precise and well understood as scientific equations, qualitative modeling tools developed for learners can help students understand alternative ways of explaining complexity in the 'human sciences' and can aid their participation in virtual communities of practice. Also, the 'concept maps' exemplified in figure 3 can facilitate representations of interrelationships in many curricular areas, as illustrated by Landow's teaching of English literature (Landow, 1992).

In summary, the effective use of learning technologies centers on fostering the knowledge and skills students need for work, citizenship, and self-actualization in the 21st century knowledge-based economy. By enabling sophisticated pedagogies that focus on guided learning-by-doing, collaborative learning, and mentoring in virtual communities of practice, learning technologies empower teachers to inculcate deeper content and more complex skills in a wider range of students earlier in their intellectual development. Beyond ScienceWare, recent thoroughly evaluated illustrations of such curricular materials include:

- *MathWorlds:* teaching qualitative calculus—the mathematics of change—in middle schools as a precursor to algebra *(http://www.simcalc.umassd.edu/)* (Roschelle, Kaput, and Stroup, 2000)
- *BioLogica:* teaching college-level genetics in urban middle schools *(http://www.concord.org/biologica/)* (Horwitz, 1999)

These types of complex projects require almost a decade of support for development and implementation, a funding stream difficult to achieve under current federal mechanisms for awarding grants.

An extensive listing of the many curriculum projects exemplifying effective use of learning technologies for instruction and assessment is beyond the scope of this testimony. An excellent compilation is delineated in the just-released National Academy of Sciences report, *Knowing What Students Know: The Science and Design of Educational Assessment http://www.nap.edu/books/0309072727/html/* (Pellegrino, Chudowsky, and Glaser, 2001).

The Likely Evolution of Computers and Telecommunications Over the Next Decade

Thus far, this testimony has discussed the implications of using all the features of today's information technologies. However, information technology presents a rapidly moving target in its capabilities to enhance human activities. Too often, federal and State planning mistakenly assumes that computers and telecommunications equivalent to yesterday's information technology will infuse society and schools far into the future. The result is learning technologies policies obsolete almost as soon as they are formulated, because they are based on older types of information technology.

Notice that, for ScienceWare and many similar technology-intensive curricular applications, the Web and Internet are just part of the technology infrastructure needed. Other components can include hand-held devices (such as Palm PilotsTM, graphing calculators, or even Nintendo Game BoysTM), home videotape players and camcorders, and cable television (soon to become digital, interactive television). In its deliberations, the Congress should consider the overall "web" of information technologies and not just the World Wide Web or the Internet.

Strategic planning and policy making requires going beyond present-day technologies to project future developments. Below is a list of devices, media, and virtual contexts enabled by sophisticated information technologies, along with the author's estimates of a conservative time frame for their technological and economic feasibility.

Functionality	Uses	Time Frame
Hypermedia (nonlinear traversal of multimedia information)	Interlinking of diverse subject matter; easier conceptual exploration, multiple simultaneous representations for learning	Current
Cognitive audit trails (automatic recording of user actions)	Support for finding patterns of sub-optimal performance	Current
Computer-supported cooperative work (design, problem solving, decision support)	Facilitation of team task performance	Current
Intelligent tutors and coaches for restricted domains	Models of embedded expertise for greater individualization	Current
Optical-disc systems with multiple read/write and mixed-media capabilities	Support of large databases; cheap secondary storage; shared distributed virtual environments	Current
Standardization of computer and telecommunications protocols	Easy connectivity, compatibility; lower costs	Current
User-specific, limited-vocabulary voice recognition	Restricted natural language input	Current
High quality voice synthesis	Auditory natural language input	Current
Sophisticated authoring and user interface management systems	Easier development of applications; reduced time for novices to master a program	Current
Widespread high-bandwidth fiber-optic and wireless networks	Massive real time data exchange	2 years
Fusion of computers, telecommunications	Easy interconnection; universal "information appliances"	3–5 years

Functionality	Uses	Time Frame
Information "utilities" (synthesis of media, databases, and communications)	Access to integrated sources of data and tools for assimilation	3–5 years
Microworlds (limited, alternate realities with user control over rules)	Experience in applying theoretical information in practical situations	3–5 years
Semi-intelligent computational agents embedded in applications	Support for user-defined independent actions	5–7 years
Advanced manipulatory input devices (e.g., gesture gloves with tactile feedback)	Mimetic learning which builds on real world experience	5–7 years
Artificial Realities (immersive, multisensory virtual worlds)	Intensely motivating simulation and virtual experience	7–10 years
"Information appliance" performance equivalent to current supercomputers	Sufficient power for simultaneous advanced functionalities	7–10 years
Consciousness sensors (input of user biofeedback into computer)	Monitoring of mood, state of mind	7–10 years
Artifacts with embedded semi-intelligence and wireless interconnections	Inclusion of smart devices in real world settings	2010+

Moving rapidly to use all the capabilities of emerging learning technologies is important for at least three reasons. First, new devices, tools, media, and infrastructures are more powerful, more reliable, more portable, and less expensive than current computers and telecommunications. For example, the costs of school computing will drop as next generation personal digital assistants (such as PalmPilotsTM) with wireless capabilities can accomplish many tasks that now require a much more expensive desktop computer with a hard-wired Internet connection. This migration to smaller, less expensive devices potentially provides powerful leverage in remediating the digital divide.

Second, next generation 'information appliances' and video games in homes, if repurposed for education, can help build partnerships for learning between teachers and families. This is vital because parental and community involvement is certainly one of the most powerful levers for increasing any student's educational performance. Third, teacher preparation should prepare students for at least a decade of work before substantial retraining is necessary. However, this is possible only if teacher preparation institutions use high-end information technologies to illustrate sophisticated capabilities.

Unfortunately, State policies often retard the adoption of new educational technologies. For example, State educational technology initiatives are frequently hobbled by designing experiences that all districts can access, even those with obsolete, low-end computers and telecommunications that cannot support advanced functionalities. For reasons of equity, enabling universal participation is important, but over time the 'floor' that States will support in its initiatives should steadily advance in capabilities. This ensures that schools pushing the 'ceiling' receive value for the advanced technologies they have implemented, and districts that are lagging have an incentive to move forward.

Also, States often provide programs for districts to improve their technology infrastructures, but typically do not include teacher preparation institutions in these initiatives. Relying on higher education institutions to provide appropriate funding for schools of education to acquire sophisticated learning technologies—and teacher preparation faculty to do battle on their campuses to receive special resources for technology—is unlikely to produce sufficient infrastructures at many institutions. Teacher preparation is frequently low on the totem pole of university technological investments, and federal funding alone cannot redress the difference.

How States and the federal government measure success in implementing technology also can hold back the adoption of sophisticated computers and telecommunications. A low-level indicator, such as the ratio of students to computers, often presents an overly favorable picture of technology infrastructure. Only when old, inadequate devices are counted differently than modern computers with advanced capabilities does a true picture emerge. Similarly, enumerating the number of schools connected to the Internet overestimates useful implementations; counting high-bandwidth connections to individual classrooms with low student-computer ratios is much accurate.

Evaluating the Effectiveness of Learning Technologies

Uverall, evaluating the effectiveness of current and emerging learning technologies is complex, because such an assessment is possible only when the conditions for successful implementation are met. An analogy to medical technologies can be made, using the contrast between an immunization and a controlled longitudinal administration of antibiotics. To be effective, the immunization needs only to take place. In contrast, the antibiotics must be taken at the prescribed dosage, with the prescribed time intervals in-between, for the prescribed amount of time. If these conditions for success are not met, the antibiotics may well be ineffective, even though this medical technology is a powerful intervention when utilized properly.

The conditions for success of learning technologies in schools are much more complex than for the use of antibiotics in medicine. These essential conditions include complementary shifts in curriculum; pedagogy; assessment; professional development; administration; organizational structures; strategies for equity; and partnerships for learning among schools, businesses, homes, and community (Dede, 1998b). Moreover, the beliefs, attitudes, and values of users are vital to the effectiveness of learning technologies—as opposed to medical technologies such as immunizations and antibiotics. Education is more like public health than medicine and presents challenges similar to public health—in moving basic research findings into everyday practice.

One reason that frequent pronouncements are made about the ineffectiveness of learning technologies is that preparing schools and teachers to use learning technologies well is a challenging process. Many of the critics of educational technology are citing implementation methods equivalent to grinding up antibiotics and smearing them over one's body, or taking the entire dose at once, or worshiping the pills rather than using them. Had American business been discouraged by similar early ineffective applications of information technology in those organizational settings and had given up on desktop computers and the Internet before learning to create their conditions for success in a corporate context, a vital component of the last decade's economic prosperity would have been lost. Creating policy frameworks that foster the development of powerful learning technologies, the delineation of conditions for their successful implementation, and the preparation of teachers and schools for effective usage is crucial for improving students' educational outcomes and educators' ability to innovate in response to the demands of 21st century civilization.

Preparing Schools and Teachers to Use Learning Technologies Effectively

How can policy makers help prepare schools and teaches to use learning technologies effectively in classroom instruction and student assessment?

Utilizing the full potential of today's computers and telecommunications to aid student and teacher learning requires developing and implementing project-based curricula similar to ScienceWare across a wide range of subject matters. Educators are far from accomplishing this, due more to psychological, political, and cultural issues than to technical or economic feasibility. For example, current State policies frequently impede this type of curricular innovation. States' curriculum standards and assessments vary greatly, but often overemphasize low-level procedural skills and recall of a wide range of facts, rather than stressing high-level capabilities for knowledge creation, sharing, and mastery (French, 1998). Because educators must race through a huge body of presentational material to meet such State standards, this precludes teachers from using project-based curricula like ScienceWare that emphasize deep mastery of core knowledge and complex procedures, including capabilities for learning factual information and low-level skills as needed. This situation is worsened by many States' mandating high-stakes tests that center on recall and recipe-following, rather than performance based accomplishment of higher level tasks (Linn, 1999).

Further, successfully implementing new educational approaches in typical classrooms is very challenging. This is particularly true for technology-based innovations, in which the cost of computers and telecommunications, their rapid evolution, and the special knowledge and skills required of their users pose additional challenges in effective utilization (Dede, 1998b). Many research-based curriculum development projects foster a few isolated innovation sites, then disappear. Needed are clinical, applied studies on adapting exemplary innovations via reflective interplay between basic research and practice, a bi-directional process that helps both sides evolve toward increasingly sophisticated objectives (Sabelli & Dede, in preparation). In such a relationship, implementation is not the blind adoption of recipes and materials for innovation developed by others, but instead the reflective adaptation of a process that enabled a similar group to succeed in improvements actualized somewhere else (Dede, 1999). However, many States have policies that implicitly assume teachers and districts will find and adapt best practices without special incentives or resources. This typically leads to educational stagnation.

In addition, project-based pedagogy is particularly challenging for new teachers, who are struggling to master instructional and classroom management strategies. If entry-level teachers are to use learning technologies to their full potential, a thorough preparation in sophisticated, technology-based instructional approaches is vital in teacher preparation programs. However, State technology standards typically do not address this issue. Instead, technology use is frequently described in such vague terms that a teacher using drill-and-skill applications is considered as well prepared under State standards as one using a sophisticated curriculum such as ScienceWare. Too often, the result of this failure of States to specify how technology alters content and pedagogy is that only low-level uses of technology are incorporated into teacher preparation and professional development programs.

Overall, current regressive strategies widely utilized for educational "reform" pose the most substantial barrier to schools and teachers using learning technologies effectively, as well as worsening inequities in our society by penalizing students who have atypical learning styles that require non-presentational pedagogies. Based on curricula such as ScienceWare, professional development for educators that moves beyond technical literacy and curriculum integration into reconceptualizing content, teaching; learning, and assessment is certainly important. However, even teachers with all these skills are now severely handicapped in using learning technologies well because they must race through a huge body of presentational material to meet broad, shallow State curriculum standards and prepare their students to do well on low-level, high-stakes tests.

Would standards for and evaluations of technology-based learning experiences help teachers find high quality curriculum materials?

Standards for and evaluations of technology-based learning experiences could improve educational practice to some extent. Teachers can always benefit from information about ways to improve their practice, just as physicians can benefit from information about effective new medical interventions. Of course, if a Health Maintenance Organization prohibits its physicians from taking advantage of medical breakthroughs, the impact of these advances on their patients is slight. Almost all teachers now find themselves in situations where the effective use of learning technologies is actively discouraged, due to a flawed model of educational "reform," so additional information about technology's effectiveness will have little leverage in improve educational outcomes and innovation. Until our society evolves a more sophisticated approach to educational improvement than "teaching by telling, learning by listening, and testing until they get it right," automating current practices with technology will have marginal benefits.

What is needed is not a regression away from standards and accountability, but "second generation" curriculum standards emphasizing mastery of core knowledge and skills, coupled with diagnostic, formative assessments that over time provide a sophisticated summative evaluation of student progress. The National Academy of Sciences report on student assessment (Pellegrino, Chudowsky, and Glaser, 2001) paints a compelling picture of illustrative technology-based learning environments and student assessments that are precursors to this model of innovation. Delineating this evolution of standards and assessments in detail is beyond the scope of this testimony; yet such a shift in educational reform strategies is needed before effective technology-based learning environments can be profitably marketed by education businesses, practically implemented by teachers, and sustainably incorporated by schools.

Creating Research Centers for Developing and Evaluating Learning Technologies

Could well-structured research centers linking scholars with education practitioners develop and evaluate effective technology-based learning experiences?

Donald Stokes' book, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Stokes, 1997), presents a compelling case for organizing federal research efforts in a manner that links basic research to the solution of practical problems of concern to society. The book's title and its central thesis were inspired by the work of Louis Pasteur, the French microbiologist who made a series of major theoretical breakthroughs by analyzing the causes and solutions of applied problems faced by farming and industry. Stokes argues that the federal government should fund primarily "use-driven" basic research—as opposed both to "pure" curiosity-driven basic research or to applied research absent a conceptual framework (e.g., Thomas Edison's work)-and presents numerous examples and suggestions to support his strategy. Do Stokes' ideas generalize beyond science into education?

The Limits of Curiosity-Driven Basic Research

Insights from many exciting federal education research programs and projects have not resulted in pervasive, widely accepted, sustainable improvements in actual classroom practice; in a critical mass of effective models for educational improvement; or in supportive interplay among researchers, schools, families, employers, and communities (Sabelli & Dede, in preparation). The lack of sustainable innovations arising from such research is consistent with Stokes' analysis of the implementation problems basic research faces when not grounded in issues of practice. Even when education research deals with the right issues, too often its results remain invisible outside of the scholarly community. The root causes of this shortfall rest partially with scholars themselves; partially with the agencies that fund educational research; partially with the distributed, loosely coupled nature of the educational system; and partially with a "quick fix with a silver bullet" mindset in our culture. Also, because policy makers are slow to take into account fundamental changes taking place in the context of educational practice, their actions often erroneously assume a dormant societal and educational environment.

Integrating current research on important pieces of the educational puzzle into next-generation, overarching models of innovation is a task that calls for different funding scales and mechanisms than typical today. Even when projects strive for greater descriptive understanding of educational and societal dynamics, their emphasis is generally on laboratory or design experiment studies that create atypical "islands of innovation." Only sizable implementation "testbeds" that deal with scalability, generalizability, local adaptation, and sustainability can advance these ideas for improvement to the next level. However, despite the fact that practitioners and policy makers are focused on exactly these issues, funding for such testbeds is currently only a minute fraction of the already small educational research portfolio. Federally funded research centers targeted to particular sets of practical problems in education and charged with developing and evaluating learning technologies that aid those problems are a means of supporting such testbed studies. Building capacity in the educational research community is also an important issue. Improving the preparation and professional development of educational researchers to reflect the perspectives above is vital for producing a sufficient number of skilled investigators to conduct these types of studies.

As studies of the processes underlying educational change document (Cuban, 1990; Fullan, 1993), systemic relationships are crucial determinants of whether the implementation of a strategy for improvement succeeds or fails in reaching its educational—as opposed to educational research—objectives. In addition, a lack of systemic analytical frameworks makes it difficult for researchers and practitioners to develop insights on how attempts at innovation interact. Also, seldom are research methodologies in use by other scholarly fields brought to bear on educational systems, even though these analytic methods have contributed to the understanding of designed, human contexts (e.g., cities, corporations) and of institutions charged with rapid technology-based improvement (e.g., hospitals). Such theory-based organizational and system-wide frameworks are needed in order to identify understudied pressure points where new ideas could lead to coherent strategies for educational improvement.

For lack of such a systemic perspective, the educational research portfolios of both NSF and the U.S. Department of Education have not permeated these agencies' implementation portfolios (materials development, teacher professional development, organizational reform). In part, this is because systemic issues have been explored almost exclusively in the limited context of evaluating systemic projects rather than deeper studies of systemic processes in testbed situations. This approach leaves undeveloped many opportunities for creating ongoing partnerships among educators, parents, employers, disciplinary experts, and communities, relationships that could lead to improvements in students' (and teachers') learning.

The common practice of conducting studies of large-scale educational interventions as "evaluations" does not create the deep research base needed. Evaluation methodologies and goals focus primarily on evidence of effectiveness; this often omits process issues and crucial variables outside the subsystem being studied. Also, such an approach removes the responsibility for practitioners and policy makers to be active participants in assessing implementation strategies and results. Too often, experiments and evaluations are imposed on schools in a way that does not foster reflective processes that could accumulate learning; yet funding for policy maker- and practitioner-centered processes of experimentation, assessment, and reflection could be a crucial enabler of sustained improvement.

How could investigators and fenders transcend these limitations in research funding and conduct? Reconceptualizing research priorities and processes to focus more on implementation studies mutually developed by scholars, practitioners, and policy makers is a promising strategy to develop sustainable impacts on practice. This agenda can be seen as driven by an interactive view of the role of the target institution. Too little emphasis is placed on research funding for *in-situ* adapting, analyzing, and scaling-up interventions and policies that, as isolated islands of innovation, have been successful in some other educational context. Even less priority is given to modeling and generalizing the coherent processes that led these innovations to succeed in design experiment settings. To achieve coherent, sustainable, and scaleable change, understanding the process of innovating (i.e., of altering standard practices) is as important as studying its outcomes (Sabelli & Dede, in preparation).

Two federal grant programs represent steps in this direction:

NSF's Research on Learning and Education (ROLE) program: ROLE funds a balanced portfolio that spans a continuum from basic to applied research. The purpose of this framework is to help enable the integration of research on learning into its broader educational and social context. The ROLE Program supports research across a four-quadrant science of learning continuum that includes:

1. Brain research as a foundation for research on human learning;
2. Fundamental research on behavioral, cognitive, affective and social aspects of human learning;
3. Research on science, mathematics, education, and technology (SMET) learning in formal and informal educational settings; and
4. Research on SMET learning in complex educational systems.

In particular, ROLE Quadrant 4 funds the types of systemic testbed research described above. However, this grant program has low resources to allocate.

The Interagency Educational Research Initiative (IERI): This funding program, cosponsored by NSF, the U.S. Department of Education, and the National Institute of Health, has as its goal the improvement of pre-K–12 student learning and achievement in reading, mathematics, and science by supporting rigorous, interdisciplinary research on large-scale implementations of promising educational practices and technologies in complex and varied learning environments. To this end, the program supports an evolving, cumulative, and integrated portfolio of research projects that, when taken together, provided a substantive corpus of effective instructional practices and a body of knowledge that informs the ways in which these practices can be implemented in real, complex, and varied educational environments and lead to enhanced student learning. An important feature of the Initiative is that all IERI-supported projects share common benchmarks that facilitate the accumulation of reliable and valid data to ensure that the lessons learned can be generalized in an optimal fashion. As such, only those projects that meet high standards of methodological rigor, are of sufficient scale, integrate technology, and are conducted by interdisciplinary teams are funded. IERI has two focus areas: Early Learning of Foundational Skills, and Transition to Increasingly Complex Science and Mathematics Learning. However, this grant program may not continue.

Lessons learned from federal funding program such as these provide a valuable foundation for designing use-driven research centers for developing and evaluating learning technologies. For example, these programs illustrate that, in designing funding mechanisms, providing phased support over almost a decade is important to enable moving new insights from early demonstrations of concept to full-scale implementation and evaluation.

Moving from Research-based Curriculum Development to Large Scale Implementation

Without extraordinary resources or heroic efforts, successfully implementing new educational approaches in typical classrooms has proven quite difficult. This is particularly true for technology-based innovations, in which the cost of computers and telecommunications, their rapid evolution, and the special knowledge and skills required of their users pose additional challenges in effective utilization (Dede 1998b). Widespread implementation of technology-based curricular innovations cannot be accomplished via one-way transmission of best practices, but instead requires and is enhanced by reflective, interpretive dialogue in a knowledge-building community (Cohen 1996).

As an illustration in the USA, Union City, New Jersey, is an example of a school district that has implemented a very effective series of educational reforms, reshaping its curriculum, pedagogy, assessments, technology usage, and links to the community [http://www.unioncity.k12.nj.us/]. Information technology has played an important role in not only enabling new types of curriculum, but also aiding dissemination, adaptation, and community acceptance. Impacts on student learning are very positive and impressive, especially since this district has a weak tax base and many challenges associated with a diverse population. Other schools have much to learn from this district's successes, which have been studied in depth.

To accomplish such transfer of successful curricular strategies, a process of 'mutual adaptation' is necessary, in which external innovations are adapted to fit local conditions and local conditions are adapted to fit the innovations (McLaughlin 1990, Ball & Cohen 1996). But what distinguishes 'mutual adaptation' from what Brown & Campione (1996) have called 'lethal mutations' in evolved implementations? Why is it and how it is that, in the process of adapting reform to local conditions, the spirit of reform is frequently lost and the result is practice as usual?

One important reason for this shortfall is that not enough dialogue to enable reflective adaptation takes place between those attempting to implement an. exemplary practice and the original innovators. Many research-based curriculum development projects foster a few isolated innovation sites, then disappear. Needed are research centers focused on a single set of practical problems (e.g., developing and implementing sophisticated technology-based student assessments). Such centers would support clinical, applied studies on adapting exemplary innovations via reflective interplay between basic research and practice, a bi-directional process that helps both sides evolve toward increasingly sophisticated objectives. In such a relationship, implementation is not the blind adoption of recipes and materials for innovation developed by others, but instead the reflective adaptation of a process that enabled a similar group to succeed in improvements actualized somewhere else (Dede 1999).

To explore a curriculum dissemination strategy that uses technology to foster such a dialogue, an NSF-funded Center for Learning Technologies in Urban Schools (LETUS) was created with four partners: the Detroit Public Schools, the Chicago Public Schools, the University of Michigan, and Northwestern University [http://www.letus.nwu.edu]. The focus of the Center is on developing and implementing strategies for embedding learning technologies in the middle school science curriculum, building on the ScienceWare curriculum described earlier. These learning technologies provide the critical support students need to engage in the complex scientific inquiry central to new national and State curriculum standards. The collaboration of the four partners provides a unique opportunity to study how to support the scaling-up of technology integration into the curriculum of urban classrooms. The Center is developing a 'Living Curriculum' collaborative relationship between developers and teachers, initially through face-to-face interaction, but increasingly through new interactive media and the formation of virtual communities for innovation.

To meet this challenge, conventional strategies for dissemination must evolve toward facilitating the adaptation rather than the adoption of reform-based innovations. Through empowering rich forms of knowledge networking and emergent intelligence that provide intellectual, emotional, and social support, new interactive media can greatly aid this process of adaptation. Parallel to exemplary practices with learning technologies in classrooms, the real power of these media comes not from automating information transmission, but from enabling students' collaborative, guided construction of meaning. Information technology is the only practical means we have of making such rich human experiences affordable and scaleable across the full population of educators. Lessons learned from the successes and challenges of LETUS could generalize to the design of future use-driven federal research centers.

Another example of a federally funded center whose goal is to move from research-based curriculum development to large-scale implementation is the Center for Innovative Learning (CILT) Technologies (http://www.cilt.org/). CILT is designed to serve as a national resource for stimulating research on innovative, technology-enabled solutions to critical problems in K–14 learning, using partnerships with education vendors and companies as the mechanism for dissemination and sustainability. Its approach is to foster and conduct collaborative research and development in areas that promise significant advances in learning. Four "theme teams" focus the efforts of the broad CILT community in areas of highest promise. Currently, these areas are Visualization and Modeling, Ubiquitous Computing, Assessments for Learning, and Community Tools. Each theme team provides direction and vision in the field, as well as a center of community.

LILT also conducts synergy projects that synthesize the important ideas and tools from all themes to create robust educational programs for use in schools. Seed grants are a unique mechanism that allows CILT to provide rapid funding to innovative and important new work. Seed grants are available within each theme team to initiate promising collaborations in directions critical to the advancement of the field. CILT-sponsored industry and school alliance programs work toward real impact of funded research on the real worlds of schools and other learning settings. These programs bring companies and schools into the CILT community through collaborative opportunities that provide mutual benefit. The barriers CILT has faced and the successes it has achieved are valuable signposts to the design of other federal research centers targeted to sustainable, effective use of learning technologies in school settings.

Through a series of projects spanning almost two decades, an example of a federally funded initiative that developed research-based curricula now widely implemented is the work of John Anderson's group at Carnegie Mellon University on intelligent tutoring systems. Carnegie Learning Corporation (http://www.carnegielearning.com/) markets and supports a series of mathematics tutors develop from fundamental cognitive science research principles. Lessons learned from this experience could generalize to other federal curriculum development projects in earlier stages of their evolution, as well as to the design of federal research centers.

The Learning Federation (http://www.learningfederation.org/) is an example of a NSF-funded group attempting to develop a use-driven research agenda focused on the problem of helping high school graduates who do not go on to college move into high-technology careers. Again, this is a case study whose strengths and limits could help design a broader federal initiative in user-focused research centers. As an initial step in developing a funding program for such centers, the analysis of these and related efforts is important.

Recommendations for Federal Policy Initiatives

In summary, sophisticated computers and telecommunications are reshaping the mission, objectives, content, and processes of schooling at every level. However, current State technology standards for teachers frequently focus on low-level technical literacy, rather than mandating that educators prepare students for 21st century work and citizenship through using new interactive media for knowledge creation, sharing, arid mastery. Also, when States fail in these standards to specify how technology alters content and pedagogy, often only low-level uses of technology are incorporated into teacher preparation programs. This situation is worsened by many States' mandating high-stakes tests that center on recall and recipe-following rather than performance based accomplishment of higher level tasks, precluding teachers from using project-based curricula that emphasize deep mastery of core knowledge and complex procedures. Isolated in their classrooms from the rest of society, teachers often have little idea of the skills and knowledge required for adept performance in high technology workplaces.

In addition, developing innovative, technology-based curricula and fostering their widespread implementation requires investments in research and dissemination that many States do not make, and in which the federal government under-invests. Further, as discussed earlier, some types of State and federal policies implicitly retard the adoption of new educational technologies.

Given all these challenges, how should the federal government and States proceed to upgrade their education policies and strategic plans to reflect the likely evolution of education and of information technology over the next decade? The recommendations below provide a conceptual framework for actions that at times can be taken by individual political entities, at times require collaboration among States within a region or nationally.

Recommendations for State and Federal Education Policy Shifts

- The federal government should fund a number of competitively awarded research centers that, as described above, are centered on use-driven development and evaluation of technology-based learning experiences. An example of such a problem-focused center would be a Center on Sophisticated Student Assessment based on the recommendations of the recent National Academy of Sciences Committee report on this topic (Pellegrino, Chudowsky, and Glaser, 2001). Having overlapping responsibilities among Centers would encourage the competitive exploration of alternative ideas and models.
- Ten percent of federal and States' total investments in learning technologies should be directed to educational research and dissemination, with emphases on sophisticated curriculum development; on coordination of research activities among States, federal agencies, and private foundations; and on implementation studies mutually developed by scholars, practitioners, and policy makers. (Just as thirty percent of technology expenditures should go to professional development to ensure that computers and telecommunications are used well, a substantial percentage should also go to creating, infusing, and studying best practices in technology-based instruction.)
- U.S. Department of Education grant review procedures should be modified to conform more closely to the high standards of process and reviewers used by NSF and NIH, and its Expert Panel on Technology should be continued as a mechanism for dissemination.
- Federal policy initiatives should promote State curriculum standards that emphasize high-level capabilities for knowledge creation, sharing, and mastery, rather than low-level procedural skills and recall of a wide range of facts. (Teachers can aid students in mastering higher order knowledge and skills only if these are explicitly included in the curriculum along with adequate time to teach these complex performances, enabling centers that develop such learning environments to find a ready audience for their use.)
- Federal policy initiatives should promote State teacher standards for technology that incorporate explicit, sophisticated performances by pre-service and in-service teachers in using project based pedagogy to help students address complex real world problems through a deep mastery of core content; higher order cognitive, affective, and social skills; and advanced computers and telecommunications. (Teachers cannot effectively use technology-based guided inquiry, collaborative learning, and telementoring in classroom settings unless they have received preparation and modeling for how to implement these sophisticated pedagogics. Such State standards would leverage the work of the research centers proposed above.)
- If States and the federal government use high stakes tests at all, these should center on performance-based accomplishment of higher level tasks, rather than on short answer items emphasizing recall and recipe following. (Teachers emphasize what will be tested.)
- State and federal measures of technology implementation should use sophisticated indicators of success, such as high-bandwidth connections to individual classrooms with advanced computers and low student-computer ratios. The minimal level of attainment of these indicators specified in State and federal technology initiatives should rise steadily over time. (Indicators of success should accurately reflect the capabilities of current information technologies and should alter as computers and telecommunications evolve.)

These policy steps will build federal capacities to conduct targeted research initiatives that enhance, via information technology, the sharing of best practices. This will aid education reform initiatives to be reflective, sustainable processes of continuing improvement that make full use of leading-edge learning technologies.

Conclusion

In the past decade, power in educational policy setting has flowed from both the federal and local levels to the States. This has not always been a positive development in decision making about learning technologies. State politicians and political appointees to State agencies are sometimes sophisticated about the evolution of sophisticated information technologies and its implications for education's mission, objectives, content, and processes; but often their responses are naïve. Coordinating collective actions among the States is also difficult, and areas such as research suffer, even though all would benefit from each State investing in this area and coordinating their design experiments around a common investigative agenda.

In particular, could similar outcomes of applying research to practice be accomplished through block grants to the States, decentralizing the responsibility of creating and funding research centers? Developing innovative, technology-based curricula such as ScienceWare and fostering their widespread implementation requires investments in research and dissemination that many States do not make. Relative to other sectors of the economy, the PCAST report documents low levels of federal funding for education research, (President's Committee of Advisors in Science and Technology, 1997). These scarce resources are not complemented by additional R&D money from States, localities, or industry, making the development of innovative technology-based pedagogical approaches and their actualization in curricula like ScienceWare very difficult. A "tragedy of the commons" situation develops when the federal government abdicates responsibility for research and development in education, as every State and locality can benefit from innovations and reflective analyses, yet no single entity has either the funding or the specialized expertise to undertake this task. Regardless of one's personal ideology about the federal role in education, decentralizing research funding to the States would result in a dramatic decrease in both quality and quantity of studies and products.

From a federal and State policy perspective, the fundamental issue in learning technologies is not whether instructional tools are more efficient at accomplishing current goals with conventional methods, but instead how emerging media can provide an effective means of reaching essential educational objectives in the technology-driven evolution of a knowledge-based economy. Just as geographically distributed workers create, share, and master knowledge, computers and telecommunications increasingly can enable all students to master more complex subjects via rich interactions with resources outside of classroom walls. Just as medical practice has shifted dramatically because of antibiotics, anesthetics, and immunizations, so the skills and knowledge required of teachers are rapidly changing. Federal and State implementation of the recommendations above to improve teacher preparation and professional development is vital to developing the pool of skilled personnel essential for enhancing educational improvement by taking full advantage of emerging devices, applications, media, and infrastructures.

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APPENDIX: FIGURES

Figure 1: The World View in Model-It

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Figure 2: The Relationship Editor in Model-It

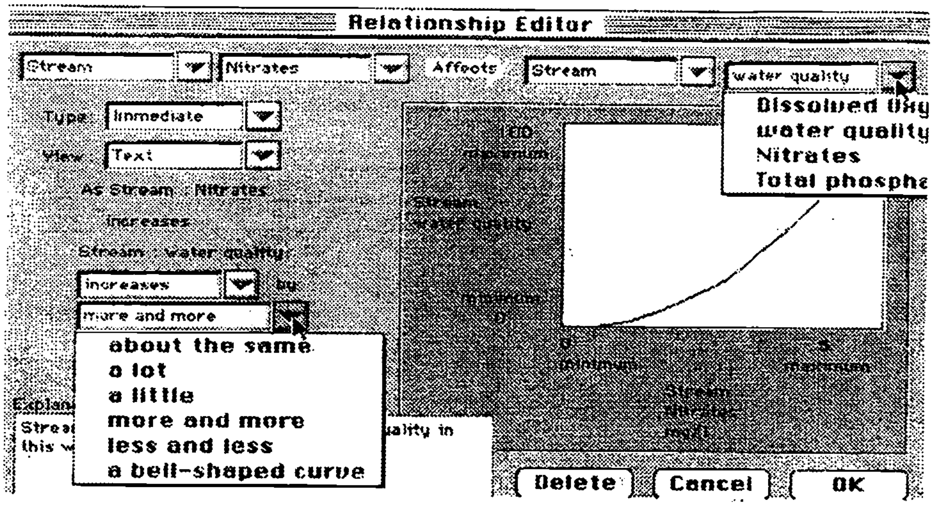
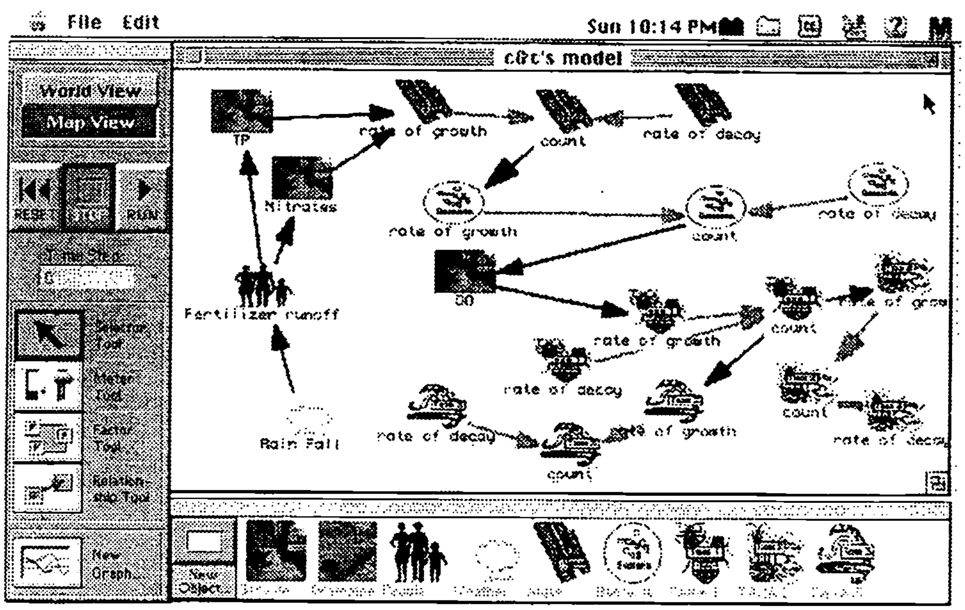


Figure 3: Part of a model created by ninth grade students



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BIOGRAPHY FOR CHRIS DEDE

Chris Dede is the Timothy E. Wirth Professor of Learning Technologies at Harvard's Graduate School of Education. His work with schools includes service on the National Technology Advisory Boards for the Milwaukee and Cleveland districts. He was the Editor of the 1998 Association for Supervision and Curriculum Development (ASCD) Yearbook, *Learning with Technology*. His research includes a grant from the National Science Foundation to develop shared virtual environments with digitized museum artifacts to aid middle school students learning science.

Chris recently served as a member of the National Academy of Sciences Committee on Foundations of Educational and Psychological Assessment and a member of the U.S. Department of Education's Expert Panel on Technology. He is also on the International Steering Committee for the Second International Technology in Education Study spanning approximately thirty countries. He serves on the Advisory Boards of ThinkLink, FreshPond, bigchalk, and World Book.

Chris's fundamental interest is the expanded human capabilities for knowledge creation, sharing, and mastery that emerging technologies enable. His teaching models the use of information technology to distribute and orchestrate learning across space, time, and multiple interactive media. His research spans technology forecasting and assessment, emerging technologies for learning, and leadership in educational innovation. Chris also is active in policy initiatives, including a spending a year as Senior Program Director at the National Science Foundation's Directorate for Education and Human Resources. His work with State decision-makers encompasses activities with the Education Commission of the States, the Council of Chief State School Officers, and the National Governors Association.

HARVARD UNIVERSITY
Graduate School of Education

Technology in Education
Chris Dede, Co-Director
323 Longfellow Hall, 13 Appian Way
Cambridge, MA 02138
(617) 495-3839

May 7, 2001

Chairman Boehlert
U.S. House of Representatives
Committee on Science
Research Subcommittee
B-374 Rayburn Building
Washington, D.C. 20515

Dear Chairman Boehlert:

I appreciate your invitation to testify at the May 10th, 2001 hearings "Classrooms as Laboratories: The Science of Learning Meets the Practice of Teaching." In accordance with the rules of the Committee about witness testimony, I am attaching this letter stating my sources of federal government funding directly related to the subject matter on which I am testifying to the Committee.

I have a two-year grant from the National Science Foundation, Directorate on Education and Human Resources, Division of Research, Evaluation, and Communication, Program of Research on Education, Policy, and Practice. This grant is for developing and evaluating multi-user virtual environments that enable at-risk middle school students to improve their science learning outcomes. The funding began in February, 2000 and ends in January, 2002; the grant total is $1,006,000.

I also occasionally do short-term consulting for various organizations that receive federal grants related to educational technology, and my consulting fees sometimes are paid from those projects. In addition, I serve on the advisory boards of several federally funded labs and centers that develop and disseminate educational technologies; I receive small honoraria for this service.

My testimony is not based on the prospect of personal financial gain or loss, but what I believe is essential to improve the quality of U.S. education. I am happy to provide any further information you wish. Thanks for your consideration.

Sincerely,

Christopher J. Dede
Wirth Professor of Learning Technologies

Chairman SMITH. Thank you, again, all, very much. With us today, I see some students in the Committee room and I can't help but think of some of my images that I thought of while you were talking. One comes from the HMS pinafore and things are seldom what they seem. I remember my freshman year at Michigan State being so disillusioned in chemistry of what I thought was absolute truths in high school and then finding out there is a difference. So there is no question that you don't take Algebra II, at least without a lot of difficulty, until you have had Algebra I.

A couple of questions. In your comments of the learning centers and the research centers, Dr. Mestre, is there a way to design these sort of multi-disciplinary centers that still can give the kind of individual research attention as far as the individual inquiry or——

Dr. MESTRE. In terms of investigating——

Chairman SMITH [continuing]. Do you think it needs to be a total separate funding?

Dr. MESTRE. Well, I think if you have large centers, they have to focus around, as Chris put it, problems to solve, as opposed to general questions. On the other hand, what I was arguing for is that, for no fault of there own, there is a lot of good researchers out there who will never become part of large collaborations because these large centers require, you know, significant collaborations among different individuals and institutions and so on. And I don't want to leave out those folks that can contribute considerably to the science of learning just because most of the funding, or most of the resources, are going to these large centers. How one can fit individual researchers into large centers through the collaborations—but there is still—I think there should be room for people to submit grants and proposals about good ideas so that we don't stifle the——

Chairman SMITH. Well, I hear you saying that as we get excited about the large centers, don't cut funding in terms of individual grant——

Dr. MESTRE. There should be mechanism to continue that. I mean, I am not arguing against big centers. They are needed as well.

Chairman SMITH. Let me—is there—are you comfortable—do we know enough about the research that has been done out there? Is there a mass of good research information that could be very helpful if we knew about it? And do you see—are you dissatisfied with our effort to, whatever, catalog, know, understand the research that has been going on in this country and other countries? And the second part of that question is trying to decide what is good research conclusions—what aren't? And let us just go down the line, starting with you, Dr. Halpern.

Dr. HALPERN. I believe we have a substantial body of knowledge. I also believe we have much more to learn. Much of our—where our knowledge falls down, we have fallen down terribly in the dissemination. I don't think we put as much effort in planning into the dissemination as we have into the projects themselves, and that should be as integral a part to the original proposals as the design sorts of issues.

Enough of that research has not been done under causal kinds of experimental designs that allow us to say, you know, when it works and when it is appropriate. So there is—while there is much—we know a good deal, there is much more we can still know.

Chairman SMITH. Dr. Mestre.

Dr. MESTRE. I agree. We have a large body of knowledge. The trouble is that it is not being used or mined to—or applied to educational reform. But I should also remind all of us here that the science of learning is really only 25 or so years old. So there is a lot more to be learned, but it would be a nice beginning to use what we already know to improve educational learning.

Chairman SMITH. Dr. Songer.

Dr. SONGER. I would also agree with my colleagues, that there is a substantial body of knowledge out there about how people learn. And other—but one of the challenges is that there isn't a tremendous amount known about classroom context and the variations necessary to adapt a particular learning study to particular learning goals. And I actually think we need a lot more research funding on research that would directly do—conduct studies more in classrooms and have large-scale impact across classrooms, so we can more directly understand that translation from the literature to the practice.

Chairman SMITH. And our ability to do enough testing so that we know somehow what research is good, as far as reaffirming what we think we know.

Dr. SONGER. Well, I am not sure I completely understand what you mean by testing.

Chairman SMITH. How do we tell which research is good and which research might not be good if we try to prove it ten times?

Dr. SONGER. I think——

Chairman SMITH. Getting it into the classroom, I would think.

Dr. SONGER. Right. Impact and learning outcomes are clearly a good way to show that it is working. However, the current testing structure is not the right vehicle to test the kind of learning we are advocating that research says we should be doing. So we want more high-order thinking, but the current testing structure is actually a pretty good mismatch to that goal in that, it doesn't often measure those kinds of understandings.

Chairman SMITH. I agree there is a vast area of knowledge. But, Dr. Dede, is there some way that we have organized and collected what is out there? I mean, if it is government money, then it is published and we can pick it up on the computer maybe. If it is a doctoral study or a research study, then do you—do we know what is out there?

Dr. DEDE. Well, there is a lot out there, but there is a saying, the devil is in the details. And, I am sure, as Members of Congress, you know what that is like. It is one thing to read a political science textbook; it is another thing to try to make legislation actually happen. The devil is in the details in applying a lot of this educational research.

John Anderson's work in cognitive science is internationally respected, and his research has had an enormous impact in schools through the application of intelligent tutoring systems in algebra and geometry. It is one of the great success stories of Federal funding in educational research. But that was a process of the devil being in the details because a teacher could read one of John Anderson's books and, even if that book were completely understood, it wouldn't say very much about what to do about that specific student in row three that just isn't getting it the first time through.

So there is a great deal that is learned by reflective partnerships between practitioners and researchers in which the theory is modified and extended and deepened through that type of interaction.

Chairman SMITH. Representative Johnson.

Ms. JOHNSON. Thank you very much. I was interested in Dr. Halpern's statement on learning and wonder if there is currently any subject or curriculum within teacher training that focuses on the learning mechanism.

Dr. HALPERN. Unfortunately, cognitive science is typically not required in teacher training. They will typically get a course in human development, maybe a course in learning. But very little of the most recent understandings of how people think actually make it into the teacher training curriculum. And, in fact, at the last page of the testimony, we have our web site from this national meeting that we chaired, and there, there are a section on using cognitive science as a basis for teacher preparation. It is largely missing. The way physicians study biology is the analogy we would like to see for cognitive science and teacher training, but we are certainly not there.

Ms. JOHNSON. When you indicated that, of course, people learn based upon knowledge they already have, we know that in many situations there is a very uneven level of grasp of information when they get to a teacher. And is there any way by which—I know there is testing, I guess, to see what level students might be on, and that is some controversy around it. But it seems to me that that would be an essential way of determining what level a student might be. Is that being used now at your level?

Dr. HALPERN. Well, we have—I say we, I am using it in a royal sense because this is not my work, but people who are working together on this project—specifically, I am talking about the work of Dr. Hunt at University of Washington, has a program called the Diagnoser, where, in fact, the way—and it asks thoughtful kinds of questions that would probe your mental model. It would allow for a diagnosis of where your conceptual understanding has gone right or is wrong, and then provides information to the teacher as to, you know, where—what is missing in an individual's mental model. And he is hoping to develop some of these models for other areas.

Ms. JOHNSON. And this has just been utilizing that particular area.

Dr. HALPERN. It is really the—we are using computer programs, because it is—knowledge networks are extensive. And we want to ask lots of questions and, based on the way you answer, I can make some assumption about your whole understanding. And then, by the way questions are guided, we could, in fact, say, this is where it was going wrong, very different from the type of assessment that we have, that the other speakers have mentioned, where—are very much lower-level kind of understanding is being tapped. You know it; you don't. This gives you much more information on an individual level.

Ms. JOHNSON. Has there been any recent studies that anyone might know, or has it been too soon to see, how the use of technology within the classrooms have impacted any performance of students?

Dr. HALPERN. Well, I would refer to Dr. Dede on that.

Dr. DEDE. Yeah. There are many studies that demonstrate that the use of technology can be very powerful in engaging student learning when the other conditions for success are present. And we have a lot of understanding of why that takes place. And the reasons go back to the kind of testimony—you have heard about cognitive science. In other words, the successes that we see can be explained on the basis of the theories that we have about learning by doing, with guidance, about making invisible things visible, about collaborative learning with technology, enhancing communication, and apprenticeships, and so on. So it is not a matter of not understanding what to do. I think the challenge is more how you accomplish it.

And to return to your question about teacher training, it isn't just what students are taught, but it is how they are taught it. To have a lecture on the importance of learning by doing—I mean, until we walk our talk in teacher education with students, being taught as we would like them to teach, we can put the content in, but it is not going to have the effect that we want.

Ms. JOHNSON. Uh-huh. Where do you think we are in attempting to—are there any sections of the country or are there identifiable schools that we are aware of that you feel that are on the mark and what percentage it might be?

Dr. DEDE. I think there are some very promising areas that are happening. I have been doing quite a bit of work within Milwaukee Public Schools, for example. This is a big city system. It has a lot of problems and challenges. It is not at a point where one would say this is a jewel in the crown of the country and something that everybody should adopt. But they are doing a lot of things right in terms of not just looking at schools, but as community as resources for students, using technology, but using it as a means to a goal, rather than as an end in itself, focusing on what students care about as a way of scaffolding their learning.

I think the real challenge is that we can find classrooms that look like that. We can even find schools that might look like that. But to find entire districts that look like that, there is a scaling-up issue that we are still very much wrestling with in trying to understand, and that is where I think these centers could help us.

Ms. JOHNSON. Thank you very much. My time has expired.

Chairman SMITH. It would almost seem that a lot of good teachers, successful teachers, are almost researchers themselves, that they have found out over the years what works and what doesn't work. That would be one area that I think we need to maybe be more aggressive on collecting that world of knowledge. And the gentleman from New York, Mr. Grucci.

Mr. GRUCCI. Thank you, Mr. Chairman. Good morning to the Panel. It is still morning. Isn't it? Yes. Good morning to everyone. And I, too, just would like to welcome the students here. I think it is great that you are showing the interest and the participation to watch what goes on in Congress, because 1 day we hope that you will be sitting up here leading this great country.

I would like to address my statement and, I guess, my question, to Dr. Songer and then I would be interested to hear the rest of the Panel as well. And the question really is in regards to—and I am not disagreeing with the need for the laboratories that you are referring to and the teaching style that you are referring to. And obviously that is going to create the need for funding to make that happen.

Yesterday, I was at a briefing where the Secretary of Education showed a pretty startling chart. And the chart showed the investment in education from about 1985 to about the present. And I have to apologize—I don't remember the exact number, but it was an astronomical figure that was invested in our educational system. And the results that benefited from that didn't mirror the chart. It didn't—meaning that it didn't show the same kind of spikes going in an upwards direction. It showed actually a pretty flat and—a flat line. And as we got closer to today, the gap between the investment in education and the results from education has been huge—there is a huge disparity.

My question is, is do you think there are programs that we are investing in that we ought not to be investing in—that we should reallocate some of those funds into some of these programs that you are talking about? And, secondly, do you think that looking at the methodology that we currently have in determining whether or not a student is understanding and learning the education—and I totally agree that there has to be some sort of a testing mode out there so that we can determine the level of skill and the proficiency of our students. Ought not that be applied also to the teachers to be—to ensure us that, (a), our investments are being placed wisely in our students' education and our children's education, and that the teachers are, indeed, proficient in the subject matters that they are teaching?

And I will point to an example, and I will relinquish my time for the answers. In New York, we have regency exams, and all through the course of the years, I see students getting B+'s and A's in their quarterly grades until they hit the regency exam. And when they hit the regency exam, most of them had failed miserably on that regency exam. And it led me to believe that the students weren't really being prepared for those types of exams, which led me to the question in my mind, are the teachers truly understanding the subject matter that they are teaching. And should we not only hold the children accountable, but should we also hold our teachers and our teaching staff accountable? And I would be interested in hearing your comments.

Dr. SONGER. Okay. To address your first question about the reallocation of funds from some areas that are currently funded to, perhaps, some areas that would support the ideas that I talked about, I can't claim that I know enough about all of the details of what is currently being funded to make a fair answer for that. But I think the real issue—the point I want to make relative to that point is that we don't necessarily need to reallocate funds for lots of different programs. I think we are going to need to try lots of different things, but we definitely need much better mechanisms for organizing the outcomes of those research programs and disseminating and discussing and learning from others' work, as well as our own.

And so it isn't necessarily that we need to reallocate from one program to another program, but more that we really need to think much more carefully about a systematic mechanism for learning from what everyone is learning—programs that try different approaches, as well as things that are more similar to our own.

In terms of evaluating teachers, I have mixed feeling about this. Clearly, we want to have high standards for teachers. We definitely want to be able to find mechanisms for supporting and working with teachers that are not necessarily teaching under the conditions that we think our children deserve.

On the other hand, there is a lot of problems with teacher accountability if it is in—for example, pay structures related to students' performance. And the reason is, is many, and I—this is a much more complicated issue that you, I am sure know much about. But that the teachers that are teaching, for example, in urban schools, are going to have students that are not going to perform as high and may include a very heterogeneous classroom, as well as students with lots of language and learning challenges. And to hold the teacher who is taking on the enormous challenge of teaching in an urban classroom, accountable for making sure that all of their students measure up against, for example, a particular state standard, one state standard, doesn't allow them the opportunity to really make a difference in that urban school.

So I think we need ways to evaluate teachers, but an evaluation mechanism that is much more extensive than a particular kind of test of some, you know, very arbitrary nature. It needs to be a much more comprehensive and systematic program.

Dr. MESTRE. Could I address the issue of assessment for a second?

Mr. GRUCCI. If the Chairman would permit.

Chairman SMITH. Go ahead.

Mr. GRUCCI. I see my time has expired.

Dr. MESTRE. I would make the statement that good assessments should drive the curriculum. The issue, I think, is that we don't have enough good assessments. And by that I mean, we know a lot about expertise, as I said, and that tells you something about what kinds of things you might be measuring. In physics, for example, we measure problem-solving ability, but expertise in physics involves lots of other things that we leave behind. So if we have the right kinds of assessment, we would be teaching all those issues that we value in—as experts in physics or psychology or whatever.

Chairman SMITH. The gentleman from North Carolina, Mr. Etheridge.

Mr. ETHERIDGE. Thank you, Mr. Chairman. And I couldn't agree more, doctor, that too many times our assessments are not the kind of assessment we ought to have that drive the curriculum and we wind up having the curriculum driven by a piece of assessment and it is done disjointedly.

Let me thank you, Mr. Chairman, for the members' testimony this morning. And, you know, we talk about funding for education and how much we have spent. Sometimes people forget we spend money on everything else. Education is an investment. And we have more children in the public schools today coming in with more problems than ever in history. And we also have challenges today in our public schools, and I think it is an appropriate one, to graduate all children. Historically, we haven't done that, and we still aren't doing it at the level we should have and we need to remember that.

I mean, I am glad to see the students here today so you can really see what a well-lighted, well-ventilated, room ought to be. Every classroom ought to be like this.

Chairman SMITH. If the gentleman would yield, maybe our Panel could develop a quick test.

Mr. ETHERIDGE. I don't think I need a test for that one. I won't ask you if your classroom is this well-equipped with technology that is integrated the way this one is, but that is what we ought to have in classrooms. So you will understand, for the students here, I was the State Superintendent of the Schools for North Carolina for 8 years before I came here. I get a little perplexed sometimes when we have such nice facilities and, yet, our schools are— we asked—I believe, Dr. Songer, you talked about it a few minutes ago—having something like 36 or 37 students for 17 chairs. And unfortunately, that is true in too many communities and too many schools.

So let me ask you very quickly before my time runs out, I do believe that physical environment is a critical part of learning for children and young adults, as much as the curriculum and the cognitive things, all we do. If you don't have a good environment, it wouldn't make it. And I think Congress has figured that out. We have a good environment. Otherwise, we wouldn't be in the conditions we are in.

So I hope you will touch on that because it puts incredible strains on teachers, on students, on the community, and all the things we do. And I happen to believe it provides a—or leads to a serious impediment in learning. And we have classrooms that are overcrowded. We have others that are just dimly lighted, et cetera, et cetera. If each one of you would very briefly touch on that? I would like to hear your comments as it relates to that, along with all the other pieces that we ask you to deal with, the curriculum and development, et cetera.

Dr. HALPERN. If I understand the question, is it physical environments that support learning?

Mr. ETHERIDGE. Absolutely.

Dr. HALPERN. And, of course, they would have to be age-appropriate, since there are different—you know, open spaces——

Mr. ETHERIDGE. Absolutely.

Dr. HALPERN [continuing]. You know, for young children, say, run here, you know, in a way that, you know, rows of chairs don't. So certainly it is different for young children than for older children and for adults. But we certainly need all of the basics that you are talking about, as well as the ability to move chairs and allow us to collaborate. If you can't move the chairs, it is very difficult to have collaborative activities. So very often, something quite simple drives it.

Dr. MESTRE. Well, we have been talking a lot about the science of learning cognitive science, and I am not sure that that—what we have talked about so far will necessarily help in the questions that you are now answering. There are issues related to motivation that we haven't talked about that are important for learning. A lot of students come to school worried about physical harm and so on. That is an important issue. How does that affect learning? I am not sure cognitive science is going to help you much in there. I could be wrong.

The physical plan of the school—if it is falling apart, that sends a message. The values of the community—all these things impact learning. And that is why measuring anything in education doesn't stand still. It is not—in my field, you can measure the spin of an electron and you get the same answer every time. Not so in education. So I don't have an answer for you, but these are issues that need to be investigated as well.

Mr. ETHERIDGE. Dr. Songer.

Dr. SONGER. Yes. I agree with my colleagues, that the resources are impoverished, especially in urban schools. At the average age of the schools in Detroit is something like 6 years to 30. The—you know, things are falling down. It is a horrible way to promote the quality of learning. In terms of what we do about it, I know there is some bills that are being passed to address that issue specifically and I just think it is very valuable and important to get that through.

Mr. ETHERIDGE. I have one and I hope we can get it through.

Dr. DEDE. My daughter is one of the students here, along with a friend of hers. I wanted her to see the strength of the American political process. I sent her and my son to Montessori school and, in part, that was not simply because of the physical facilities, but the physical manipulatives, the wonderful kinds of objects that students get to interact with. Part of our challenge now in learning technologies is understanding virtual spaces and the kinds of poises that students can be together that are shared virtual environments. So I think we face some very interesting design challenges that I hope this kind of research money can help us to understand, challenges that involve linking physical spaces to virtual spaces for learning.

At Harvard yesterday, I was part of a provost campus-wide workshop. The Graduate School of Design was doing some wonderful things with virtual and physical spaces for their students. I could see applications to pre-college. I hope we can get there.

Mr. ETHERIDGE. Thank you. Mr. Chairman, I know my time has expired, but I thank you for this. And I think—I asked that question simply because we can't deal in one specific piece. It is a very complicated piece and all of it has to fit together one way or another if we are really going to do the job of providing quality educational opportunities for all the children. Thank you.

Chairman SMITH. Thank you, Mr. Etheridge. The Vice Chairman of the Full Science Committee, the gentleman from Minnesota, Mr. Gutknecht.

Mr. GUTKNECHT. Thank you, Mr. Chairman. And, first of all, you have referenced the students here, and let me just introduce them to you. They are students from Winona State University in my district. Linda Seppanen, on my far left, is the instructor who is keeping them together for this week. And I think they have had a very interesting and very educational week here in Washington and learned a lot about the city and the history of this great country. And so we are delighted to have them here.

I have a very limited amount of time and I guess I have more of a comment than a question, but I would like to have you respond to this. I thought my memory was good, but I had—I checked this on the computer just to confirm. Let me read this to you. "In 1854, the family settled in Port Huron, Michigan, where he attended school for 3 months. This was his only formal public education. His mother continued his education, teaching him reading, writing, and arithmetic. She also read to him from well-known English writers, such as Edward Gibbon, William Shakespeare, and Charles Dickens." Any of you know who that individual was? He was our greatest scientist. His name is Thomas Alva Edison.

And I want to really refocus this just a bit because I do admire what you are doing and I think it is important, because I think research and learning is something, as we go forward in the information age, is going to be incredibly important. But I also believe very strongly that success leaves clues. And if we miss those clues, I think we miss a very important part of the story. And one of you just referenced the point that a lot of this is about motivation.

You know, I think two of the clues that you find of successful people, and particularly people who are successful in science—one is, they are very curious people. And, number two, and if you study Thomas Edison at all, you find that he was incredibly persistent. I think those are two things that you cannot leave out of your research as we begin to look at why some people excel in science and some people find it very difficult. And it seems to me that if we miss that, if we don't get at—how do we motivate people to become curious? How do we get people to get interested? And that has certainly got to be part of the equation.

And finally, as my colleague from New York said, I was at that breakfast meeting yesterday, as well, where the new Secretary of Education showed us some charts, and they are a bit troubling, when you compare what we spend in the United States to what is being spent in other industrialized nations on a prorated dollar-for-dollar equivalency. We certainly are prepared to spend whatever it takes to make certain that our kids get a quality education. But it seems to me that, as a member of the Budget Committee, we need to make certain that we are getting our money's worth. And so we want to do all we can to help you to make certain that the next generation of Americans does get its money's worth. And perhaps you want to comment on anything that I have editorialized on here so far, please.

Dr. DEDE. Well, a couple quick points. One is, I don't think that we are here asking for more of the same. I don't think that we are here to say, we are doing a great job. We just need more money. Give us more money and we will get it done.

Chairman SMITH. Thank you.

Dr. DEDE. I think that you have documented effectively the fact that there is much money that is spent on educational research that is not leading to a payoff. And the different kinds of testimony that we have presented have sketched some of the reasons why that might be true, indicated how refocusing some of the research might well lead to greater productivity in this area. So, yes, I think it would be a mistake to treat this as a plea simply for more resources because without that refocusing occurring at the same time, the greater resources would not have the kind of leverage that you would like to see.

I like very much your comments about what is required for success. I have read things like the autobiography of Richard Feinman, where he talks about how excited, as a boy, he was by things like taking radios apart and putting them back together. And one of the things I find very troubling now about even our schools that succeed today, is that students come out and they know a lot of stuff. The "A" students can do well on these incredibly detailed tests, but the joy of learning and the love of learning and the curiosity and the motivation often have been burned out of them because they have been stuffed with knowledge like a goose. And, you know, sometimes less is more. Sometimes if we ask students to learn less, but learn it more deeply and learn it in a way that really kept that curiosity burning in the way that it burns in our 5- and 6-year-olds, we would have a lot more when we ended high school than what we have now.

Chairman SMITH. Dr. Halpern, you had—you wanted to react to that.

Dr. HALPERN. Yes. I guess a couple of things. Our world is much more cognitively complex now than it has ever been, and education is much more critically important. I don't think Edison could have gotten by today as he did then on so little formal education. The people who, a generation ago, wondered should I finish high school, now realize that they are going to need a college education to even enter the middle class. But you are certainly right about the motivation and the persistence in five—that is in all of our writing. In 5 minutes, I guess that was the part that wasn't there. But there is no doubt that—and we are really talking about education for all students, not just the most extremely gifted who almost, regardless of what we do to them, will come out wonderfully. It is everybody else. And how do we like that motivation?

And, certainly, it is also hard to make sense out of those funding kinds of issues that you talked about. The students have changed in the intervening years. In California and many other states, the number of people for whom English is their first language has substantially declined so that we have, you know, a different number—different students in our classrooms and the demands of them are different. So it is so hard to make those equations. But you are right about not continuing business as usual, and I think that is really what we are here for.

Chairman SMITH. The Chair recognizes the gentleman from Washington, Mr. Baird.

Mr. BAIRD. I thank the Chair and I thank the Panel. In my life before being in Congress, I was a clinical psychologist and spent a fair bit of time on cognitive psych. So names like Jerome Bruner and Vygotsky and Piaget and whatnot are pretty familiar to me. But I want to ask a little bit different question. And I also was a university teacher and spent a lot of time in high school and junior high classes.

One of the impressions I gather from those visits and from my own studies of cognitive psych is that, teachers today are up against a real puzzle, and that is that the medium of television—and I refer to the medium, not the content here—I believe creates a negative cognitive set that is anethetical to critical inquiry. And what I mean is, it creates a passivity which is contrary to the way human beings normally learn through literally millions of years of evolution. And once that set is established of passivity, it seems to be extraordinarily difficult for our teachers to overcome the passivity. I wonder if you have got any insights.

My understanding is there is relatively little research on this issue. We focus on violent content, etcetera. But the passivity of the medium, I think, is a real obstacle. Any thoughts on that?

Dr. MESTRE. Well, I have heard my colleagues complain that I can't get the students' attention the way I used to when I used to lecture to them 20 years ago. So I agree with you. There is some research on how students watch television, how they learn from watching television. I am not an expert at that, but there are people who know something about that. I agree about the passivity. And what is different now also from Edison's time is, he could tinker an awful lot and now——

Mr. BAIRD. That is the point I am making.

Dr. MESTRE [continuing]. There is no motivation to tinker because you get entertainment by sitting down and watching it. And so the students are certainly learning differently than they did many years ago. And how we can change that to be more self-motivated to learn, I don't know of an answer to that and it would be nice to have one.

Mr. BAIRD. That is precisely the point I am making. And we focus so much on the content and violent and sexuality, which I think is a problem, but the greater subtle problem, I think, is the passivity and the lack of tinkering.

A somewhat related question—as we look at all the—I think there is wonderful things to be learned, and I really do compliment the Chair for raising this issue. I think it is unusual that these kinds of issues are raised here in Congress, of cognitive and neuroscience and education. But it always also seems to me that time on task is one of the fundamental variables. And when we look at shortcuts to that, to some extent, we may be being dishonest. It just takes you a while to memorize your verb forms in Spanish and it takes you a while to master your multiplication tables. And I don't know if there is a shortcut for that. Any thought on the time-on-task element?

Dr. MESTRE. The first indicator of expertise—time on task.

Mr. BAIRD. Dr. Halpern.

Dr. HALPERN. A lot of our old standards, like time on task, distributed practice, are still as true as they were 20 years ago. One of the things that some of these interactive programs do when they are done well, is that they increase time on task, as well as cooperative learning and those were—they are all under the buzz word active learning, which is in response to your question about the passivity, and they all increase. They all require activity. They increase time on task and they distribute learning. So clearly, those are the kinds of basic principles that, you know, are still as true as they ever were.

Mr. BAIRD. One final question, if I may, Mr. Chair. One of the things that also impresses me is that we tend to conduct our educational approaches if the normal curve was a fiction instead of a reality. And that—by that I mean, we tend to teach toward the middle and leave the ends flounder and we act as if we can bring the low end up to the level of the high end with some gee-whiz gismo, or as if teaching to that middle is going to somehow reach the low end. Particularly, this concerns me as we talk about testing, mandatory testing, on a yearly basis and evaluating our faculty or our institutions. Any thoughts on whether we ought to revisit the meaning of the normal curve and educational policy?

Dr. DEDE. Well, I think the heart of really powerful learning is individualization. That is why the strongest studies in educational research are of individual human tutoring. And nobody can get gains like an individual human tutor because it is affective and cognitive, because it is tailored to the specific needs of that person at that time. I think what is exciting about many of the kinds of teaching techniques that are being developed and many of the kinds of learning technologies that support those is that they are capable of that kind of individualization, even in a group setting. And things like the Intelligent Tutoring Systems of Anderson are an excellent example of that.

So we can do this better than we are doing it now, and that is a much more productive way of thinking about the challenge of how to help all students succeed than just sort of dividing students into blocks and saying, well, here is a remedial group and here is an enrichment group and here is your typical group, and so on.

Mr. BAIRD. I would be very interested—and I know my time has expired—but I would be very interested in some cost benefit analyses about if we can tailor that individual tutoring with appropriately designed technology to individuals, if we could reduce drop-out rate, improve performance, possibly reduce crime and substance abuse, etcetera, it might be money well spent. Thank you, Mr. Chairman.

Chairman SMITH. The gentleman from Connecticut.

Mr. LARSON. Thank you very much, Mr. Chairman. And let me also thank you for conducting this hearing. You know, I am—I serve on the Armed Services Committee, as well as the Science Committee, and I am always struck by the fact that if this was a discussion in Armed Services, there would be no question about the money, no question about the need, and then it would be how much money can we send you, and are we giving you enough. And, yet, I firmly believe that we, in essence, need a technological marshal plan for the Nation if, in fact, we are going to be able to individualize instruction for all of our students and leave no child behind. I think Washington is, these days, is filled with a great deal of acrimony about leaving no child behind, about accountability and testing, because those are all the easy things that we can take immediate credit for.

I am impressed by the level and depth of your testimony and how difficult the problems that we face in education are. And, as several on this Committee are grappling with, you know, trying to get our arms around this situation, I am wondering—I think it is pretty intuitively obvious that the defense of the Nation and its continued economic prosperity and our public education system, are linked and tied to our future. Yet, I think we have got our heads in the sand as a Congress in terms of looking at what we need to do within our school systems. There needs to be a fundamental retooling and restructuring. And Bobby Etheridge talked about the facility that we are in. You know, our laboratories, if you will, for education, our school rooms, are in woeful neglect and not nearly up to speed so that we can compete in a global knowledge-based economy.

Now, in some of your testimony, Dr. Dede, is, will these centers be a springboard or should the country plunge forward? Just like we were able to put a man on the moon with the same kind of can-do attitude that we are going to take and reconstruct an education system that is based on a knowledge-based economy with information and data being the future currency. And that is how we will continue to thrive and prosper. I would be interested in your comments—any of you.

Dr. DEDE. Well, first, I very much I agree with you that this is not something on which we should wait and eventually, when we have research results, then move forward. In fact, as I indicated in my testimony, I think there is good reason to believe that without more fundamental changes in our approach to education, that the seeds generated by these research centers would fall on barren ground in terms of the opportunities for their application.

One of the things that is most exciting to me out of the advances in cognitive science and learning technologies has been the extraordinary things that we see from all students when they are really taught in powerful ways. Two of the things that the National Science Foundation has funded illustrate this. Sim-Calc is a program for teaching qualitative calculus, the mathematics that have changed to middle school students, as a precursor for algebra. Biologica is a program for teaching college-level genetics to middle school students as a way of understanding something that is now becoming very important within society, within the human genome. And we find that middle school students, all middle school students, when they are taught well, are capable of this kind of achievement.

So both higher standards for what we believe students can learn and the kinds of structural changes that you are describing are necessary, are very important if we are going to harvest what these research centers might create.

Dr. HALPERN. I would make the point that our strongest national defense is an education citizenry. I would also make the same argument for anyone who is on the economic indicators, that there is a clear literature that links educational outcomes and education level to the economic health of our country. I think this is a defense issue and an economic issue and that we need very strong leadership from Washington to really make it a coordinated national priority.

Dr. MESTRE. I would like to comment on your issue about if we well-equip the classroom can we throw money at it and do well. I would ask—well, are the teachers capable of teaching this kind of environment? That is an important issue. You can have something wonderful, but if it is not used in the way to maximize learning, then where are we.

Also, in terms of teachers, they have a tremendous workload and how much time is there for them to look at research and learning—how it might impact their teaching. All these things are as important as the facilities that they teach in.

Mr. LARSON. Well, I agree that teacher training is essential. We have had Dan Goldin in front of the Committee, however, talking about intelligent agents. The same kind of technology where, in the workforce today, ultimately, an individual is going to be conferring with an intelligent agent that takes on human form and has the same cognitive and effective abilities to make decisions and guides that person through there. It doesn't seem like universally we are anywhere near that in public education. But I will tell you what, we will do a lot to say teachers at fault. We will do a lot to say that we are spending too much money in this area.

And there is a lot of truth to a number of these arguments, but the reality is, if this Nation doesn't wake up and protect a fundamental interest that has got us to this position today, we are in a sorry state. And we need—we didn't—not retooling the automobile industry has been an indicator that everyone always points to. Not retooling public education to the fact—and that includes the training of public teachers and the preschool work that needs to be done—but not recognizing the world that we are living into today and conforming, will be a major loss for this country. And it is an investment. It can't be done locally because the tax base just won't allow it. We—the Federal Government needs to step in.

Chairman SMITH. The Chair recognizes——

Mr. LARSON. I am sorry.

Chairman SMITH [continuing]. The gentleman from California——

Mr. LARSON. Sorry.

Chairman SMITH [continuing]. Mr. Baca.

Mr. BACA. Thank you very much, Mr. Chair, for having this hearing and thank the panelists as well for being here. I think, like most of us, we believe that we should be investing a lot more money in education, and I don't believe that we have invested enough in education. And I believe that we have got to prepare each and every one of our children for the 21st century and—as we look at technology and the use of technology. And we also look at what is important for a lot of us, as we look at new instruments and new tools that are being used, it is also very important that we have critical thinking, because that is one of the processes that is missing in this ingredient, is that our children are not thinking like the way most of us were educated in the past. We need to also build their self-esteem, their motivation, and their confidence in order to be able to do what is necessary.

And from our point is that I want to make sure that we continue to invest as much as possible in education and to make sure that we leave no child behind, which means that we have got to have the tools and the instruments in every one of our schools to make sure not only a center, but also that centers are available for our children can go to learn because then some will advance while others will be left behind, so how then can we compete in this global economy.

So my questions are—a couple of questions for Dr. Dede and Dr. Songer. The availability of computers and web site materials have grown such that, at the present, teachers with an overwhelming array of potential teaching materials, making it difficult to identify the really good online resources—how can standards and assessments of computers and web materials be developed to reduce individual burden to teachers and to help them find quality materials? Either one.

Dr. SONGER. Well, actually, through the National Science Foundation there are several boutique projects that have addressed and come up with solutions to the problem that you raise. There are organized search engines, for example, that are specifically tailored for children and particular learning goals. And they can help teachers. The problem is that we don't have the mechanisms to get these boutique-developed projects out into, you know, millions of learners and we really need an infrastructure and an organizational dissemination mechanism like the national centers we have talked about, I think, as a mechanism for getting things that we know are working and products that are having impact on a small level out much more broadly.

The second point I wanted to make related to this is that you mentioned the importance of developing both skills with technology and critical thinking. And I think we have a fundamental research finding that can help us understand ways to address both of those at the same time. And that is the research that talks about teaching much smaller numbers of concepts, as they do, for example, in Japan and other countries, as compared to the United States. So we know, for example, that an eighth grade science textbook in Japan has—covers eight major concepts, whereas an eighth grade science textbook covers something like 68. So what we really need to do is use technology, in part, to develop a set of resources that will focus on a smaller number of concepts and allow students to really work with them for enough time that they can get to the critical thinking skills and understandings that we envision.

Mr. BACA. But in order to do that then that means that class size reduction is so important too, as well, because that makes it very difficult if you have got a good instructor, but you have got 35 to 45 students in the classroom. Is that correct?

Dr. SONGER. I don't necessarily think that you have to have a small class size if you have resources that are well-organized. And, in particular, as Dr. Dede mentioned, there are a growing number of resources that can help students learn in small groups or more on an individual basis, and we are working on ways to help teachers manage that even within large class sizes. And we are doing that relatively successfully within Detroit Public Schools, which has large class sizes.

Mr. BACA. Uh-huh.

Dr. SONGER. So smaller sizes clearly help with some of these issues, but it isn't necessarily only——

Mr. BACA. But it does help when it comes to self-confidence and self-esteem. If you are put into a large environment in that group, it becomes a lot more difficult. If you break them up into the categories that you said, yes. But for someone that maybe has not been able to comprehend, it becomes very difficult for that child in terms of that self-esteem and that confidence.

Dr. SONGER. Well, in the best of cases, the teacher becomes the facilitator and the resource—technological resource can help with some of the guidance of the students' learning——

Mr. BACA. Uh-huh.

Dr. SONGER [continuing]. So that that allows them to get more individual tailoring to their needs in a way that it doesn't have to all fall on the teacher themselves.

Mr. BACA. Okay. I have one other question—and I will read the statement and then I will ask the question. In 1996, the report on Education Technology Commission by the Office of Science and Technology Policy, recommended, as the highest Federal funding priority, support for large-scale demonstrations of school programs using advanced technology with careful assessment of educational outcome. This was also the recommendation of the President's Committee of Advisors on Science and Technology in 1997. And it was also endorsed by the recent Web-based Education Commission Report. Do you agree with this recommendation? If so, what are your thoughts on how to implement it? And, on the level of resources, what would be required to do so? Any of you?

Dr. DEDE. Well, first, absolutely, I think many of us agree with that recommendation. Second, a lot of the testimony has indicated that that can't be accomplished by saying to existing funding programs, please give more emphasis to this area, as I think has been done in the past, because existing funding programs tend to fund what they have always funded. So what we are suggesting is that a new initiative centered on this kind of research and investment will be more likely to produce the kinds of shifts that have not happened over the last 5 years than another admonition to existing funding programs to try to do a better job with use-driven research.

In terms of what it is going to take, I think that it is going to take, perhaps, initially, 100 to $200 million, scaling up from there as the research capacity expands, to be able to take full advantage of the resources and use them wisely in these studies. And I think it is going to take funding mechanisms that are of the kind that we have described in our testimony, that are competitive, that are problem-centered, that begin with what practitioners struggle with and then look back to basic research for ideas about answers.

Dr. BACA. Thank you. I—you know, basically, I agree with you. But part of the problem that we have is that the argument from one side usually comes—here is a mandate that we are requiring, but no Federal funding to back the mandate, which is a problem that we have and hopefully that we can come together on a bipartisan and support the funding along with a mandate as we look at leaving no child behind and allowing them to be creative in thinking and being prepared to deal with what needs to be done and doing the teacher training, the staff development, and the administrative training, as well, that is very important as well, and being in uniform in terms of what needs to be done. But I agree with you, you know, from my perspective.

Chairman SMITH. And, Congressman Baca, I think we will do a short second round if you want to ask more questions. I—exploring this a little further, last week at our hearing, Dr. Parravano from Merck and agreed to by Dr. Sadler from Harvard, said that they thought that students between the kindergarten and third grade was the time period that those students generally would get their inspiration or excitement or interest in math and science.

And so how much research are we doing to—if that is true—and maybe comment on whether you think it is true or not—if that is true, then are we doing our research to have that kindergarten, first, second, and third-grade teacher know the things, do the kind of things that can excite those students? Where is our research? And as we decide where to spend the money on research, as the National Science Foundation decides what sounds like a good idea for research project and what doesn't, is there a danger of us being too technical and maybe not looking at some of the inspirations that can be accommodated with a greater interest—inspiring a greater interest in those younger students?

Dr. MESTRE. Yeah. I just don't have a good answer to your question. What seems to be known is, for example, girls and boys do equally well in math and science until a certain point—middle school, and then there starts to be major deviations. So that is another issue that I am not sure we understand well and it would pay us to understand well. Though I agree we need more work.

Dr. DEDE. I think——

Chairman SMITH. So do you think it is true? And maybe that is not your field of expertise. But if it is true, then we should be looking at the kind of techniques or research. I mean, certainly, students, people learn in different ways as they get older. So a research effort and application that might be a great effort for high school students, might not be the same application for those early grades.

Dr. DEDE. Well, I think the early grades are extremely important. And I think that young children bring a lot of natural curiosity and motivation that often schools lose rather than reinforce. I think one particularly unfortunate thing that is happening now with the current movement for educational reform is elementary teachers are getting told it is all reading and math. You know, make sure the kids can read; make sure that they can do basic math.

And so things like science are getting squeezed out of the curriculum by the increasing pressure to just drill, drill, drill on reading and math. And while it is important to be able to read, and it is important to be able to do mathematics, more creative curricular approaches to teach reading in the context of learning science—math and the context of learning science, are ways of doing both and rather than putting teachers into an either/or situation.

Chairman SMITH. And let us go maybe a little further in sociology and go to the influence of parents. Should we be doing some research in good techniques to excite the parents because I think, from our experience, generally in education, if the parents are interested in math and science and not fearful of it, then there is a greater likelihood that the students are going to do well in math and science. And so, you know, I suspect that part of our problem is the fact that these kinds aren't in that kind of home environment that gives them that kind of encouragement and excitement. Yeah—Dr. Halpern.

Dr. HALPERN. I am excited about the idea of family learning centers. We really are moving to the need for life-long learning. We each have to upgrade our own learning and skills, you know, throughout life. I think it used to be more of an empty phrase and I think it is a reality. Everyone must continually be learning new kinds of computer skills to move forward or even to maintain their own job. We could be doing a lot more in bringing families together in learning where, in fact, we would offer, you know, continued learning to parents and, at the same time, at the same site, have learning centers for their children. Parents are critically important and they are—have been left out of what we have talked about, and where we incorporate them, I believe the better chance we will have.

Chairman SMITH. I did a survey in three of my eight counties for kindergarten through sixth grade, and over 50 percent of the students come from nontraditional families, most of which are single mothers. And so the challenge of raising kids today, if you have got two parents, let alone one, has got to somehow have an effect on those kids' willingness, interest, ability to learn. And I don't know if we are doing research in it. Dr. Songer.

Dr. SONGER. Oh. I was just going to agree with you and say that what is happening in terms of one mechanism for having more family—promotion of family learning, is happening in some urban areas, for example, Pittsburgh and Detroit and other areas, where they use the technology resources as a facilitator for family learning. And they actually use the schools and where the computers are as community centers for parents to come in and do homework and even update their own resumes using the computers in the schools after hours. So there are some actually very imaginative ways to get more family involvement in student learning in some of the urban centers, but these are really just pockets of success and we clearly need much—you know, better mechanisms for having these processes get distilled throughout.

Chairman SMITH. If—let us assume for a moment—and I will finish with this—that it is true that the child between 5 and 10, or maybe between 2 and 10, whatever, has the potential—a greater potential to be motivated and interested and, therefore, does a better job in math and science—are we doing any research for that grade level? Are we—are teacher universities doing anything to deal with that? I am looking for maybe what we should do in terms of expanding research or expanding a greater effort.

Dr. SONGER. The IERI initiative that I am funded under does have one specific focus area that is K through 6 learning, and they are looking specifically at reading, math, and science within that—those age populations because they are also recognizing that we actually don't, I don't think, have enough—quite as large a body of research on the learning in those early years. I guess that is it.

Dr. DEDE. I think that one thing that we do know from research is that we face a real challenge at the elementary school because the teachers are responsible for all subjects, and so many teachers have very little preparation in science or—and, therefore, have trouble using the kinds of subject-specific pedagogy that the Panel has described. And part of the promise, I think, of the learning technologies is to make other kinds of resources available to those teachers—parents who know something about science who, through technology, can be resources within the classroom, distance experts who can be resources within the classroom. There is a lot of creative work that could be done with helping compliment the skills that elementary teachers have in areas that weren't the primary source of their preparation.

Chairman SMITH. Again, thank you very—all very much. We have kept you a long time. Maybe just briefly, for 1 minute, any other issues that you would like to mention or suggest as we proceed in writing our authorization bill for the National Science Foundation.

Dr. MESTRE. One thing that I threw out and nobody bit on was the issue of how scientists teach science to all students at the university level. And I think that is something we actually have to look at carefully because it sets a model for what teachers, perfected teachers, are going to do when they leave. And as long as they observe teaching of a certain type, they might go and mimic it, which is not necessarily what we want.

Chairman SMITH. Okay. Good point. Dr. Halpern.

Dr. HALPERN. Yes. One thing I hadn't mentioned, but believe to be important, is a look at the actual reward structures. Are we rewarding faculty for engaging in these activities and, in fact, not punishing them?

Chairman SMITH. Thank you. With that, again, thank you very much. The record will be held open for 5 legislative days for any additional comments or insertions by the members of the Subcommittee. And, if our panelists might agree, there is a few unanswered questions that staff would like to know your reaction to, if we might send them to you. And with that, the Committee is adjourned.

[Whereupon, at 12:30 p.m., the Subcommittee was adjourned.]

APPENDIX 1: Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Answers to post-hearing questions submitted to Jose Mestre, Professor of Physics, University of Massachusetts, Amherst

A—Post-Hearing Questions Submitted by Chairman Nick Smith

A–1. When a new theory of education practice is developed, how much research is typically done to demonstrate that the theory is "correct" versus rigorously comparing the new theory to others? How can we build research centers and communities that conduct non-biased research on teaching and learning in spite of pressure to embrace a particular theory or practice?

Proposing that there is or will be "a" theory of educational practice is interesting, but probably not realistic, for a number of reasons that are based on what we know about learning and what we know about behavioral science. Educational practices, as it was pointed out in the National Academy of Sciences book, *How People Learn*, cannot follow the old quest of searching for a "one size fits all" remedy to effective delivery of educational practices. We are a very diverse nation, and while I would agree that we can have singular goals of excellence and effective learning for everyone, there are many factors that give meaning to learning experiences. These are termed "mediators of learning," to indicate that knowledge is not poured into the cranium in ready-to-use form by the student. Rather, culture, age and socio-economic status of the learner, knowledge possessed by the teacher, the content that is being learned, the home and school languages of learners, the support systems in the community to support learning are all factors that influence educational practices. And because of the complexity of the task, it is important to hold each and every educational innovation up to the scrutiny of scientific validation. This is not a search for "the correct theory," but how science proceeds—hypothesis testing against theory and accepted practices.

In education, theories evolve from data on learning experiments and observations of how people learn. Hence, the issue is not so much whether or not a theory is "correct," but rather whether or not the theory is consistent with our observations and understandings about learning. Research centers in education, as in any other science, should be in the business of gathering data on learning and teaching, and using those data to refine or recast theories of teaching and learning so that the theories are consistent with observations. If a research center "embraces" a theory and sets out only to gather evidence to "prove" the theory, then that center is not a true research center in the scientific sense. The major difference as I see it between research in the sciences and research in education is that in education, it is extremely difficult, if not impossible, to control for many of the relevant variables that enter a learning/teaching experiment (e.g., the factors listed in the previous paragraph confound results).

A–2. Approximately what percentage of existing curricula and textbooks have undergone the kind of rigorous assessment required to evaluate their impact on student learning and to determine how best to use these resources for optimal classroom instruction? What models exist for rigorous assessment of curricula and textbooks for their impact on student learning?

Textbooks are driven much more by market forces and tradition than by scientific evidence on their effectiveness. Despite publishers' claims, it is rare that a textbook undergoes field testing that goes beyond peer review or questioning teachers' satisfaction with it (and that is often limited to the teachers' guide and sets of test questions, and not focused on the book content). So, rather than providing an arbitrary percentage, let me just say "rare" versus commonplace is how I would characterize rigorous textbook and curriculum evaluation.

This raises an interesting dilemma—how does one change the market forces so that textbook design reflects more accurately our knowledge of learning? We have a vicious cycle at work that is hard to break. Most textbooks that are based on research on learning (e.g., many of the NSF-funded curricula fit this category, including a high school textbook developed by our Physics Education Research Group called "Minds-On Physics" and published by Kendall-Hunt) not only look different from traditional textbooks, but are intended to be used within a different kind of classroom environment (e.g., using active learning or inquiry modes, rather than passive lecture modes). If teachers teach traditionally, they are likely to select a traditional textbook that fits traditional methods of teaching. Using an innovative curriculum based on research on learning within a traditional instructional style is a recipe for disaster. So, what we need to do is to find a way to educate teachers on ways of teaching that are consistent with research on learning, and *simultaneously* provide textbooks and curriculum materials that support the new teaching styles.

So long as teachers continue to learn from traditional textbooks and to teach in traditional ways, we will not change the market forces that drive textbook design and production. We also need to keep in mind that textbook publishers are not the villains—they simply satisfy market forces.

Finally, in terms of models for evaluating the impact of curricula on student learning, most NSF-funded curriculum development projects (including our own Minds-On Physics) require rigorous evaluation. Hence, models exist for doing this, but large publishing companies certainly don't evaluate their products in any meaningful ways.

A–3. Proponents of inquiry-based and discovery learning in the U.S. correlate the use of these methods in Japan, Singapore, and Korea with the high scores these students receive on international comparisons such as TIMSS (Third International Math and Science Study). Has the use of inquiry-based teaching methods led to a significant increase in test scores for American students? What elements might be missing that would explain the limited success of inquiry-based learning in the U.S.?

I particularly like this question: it's not a trick question, but I think that the answer contains some surprises that are seemingly counter-intuitive. It's important to separate inquiry learning from the TIMSS issues. Let me mention the latter first: We Americans are always embarrassed by the TIMSS results, but are not too surprised when we learn that students in Korea, China, Japan, and Singapore do so exceedingly well on the math and science sections in comparison to American students. In a speech this past April, Akito Arima, former Japanese Minister of Education and Science, explained that the high performance by these Asian countries concern him greatly. What Dr. Arima was referring to is that composite scores on math and science do not reflect fully how the Asian students emerge from their learning experiences. When given questionnaires, the Asian students uniformly state that they *do not like math and science.* By contrast, the American students come out of their educational experiences with much more favorable attitudes. The implications of satisfaction with learning have serious consequences for the math and science courses that they will elect to take in the future and the careers that these students will eventually choose. This is why Dr. Arima is so concerned: he believes that the emphasis on achievement has not been balanced with an appreciation for the science and math that the students are learning, albeit they are learning their lessons well.

This brings me to the second, or really the first, part of your question regarding Inquiry Learning. Depth-of-understanding is the goal that teachers have for learners, and there is strong evidence of the effectiveness for allowing students to explore a domain of learning and to learn how to frame questions about that topic. Now, obviously, some things like historical dates and multiplication tables need to be taught directly. But the core of Inquiry Learning is to identify the major principles and concepts and to coach students in the art of applying those principles and concepts to appropriate contexts. For learning to be self-sustaining and lifelong, the students need to learn the frameworks for searching for answers. I believe that both depth of learning and satisfaction with learning are the goals we want to achieve.

I should mention other factors relevant to explaining the big performance differences between US students and Asian students in TIMSS. Effectiveness of inquiry-based learning depends highly on the teacher's ability to implement this method of learning effectively in the classroom, and in the U.S. we have far to go in terms of helping teachers acquire the knowledge and expertise to become coaches of learning. Another important factor that contributes to these performance differences is time on task. There is evidence that Asian students spend considerably more time doing math and science (many while attending after-school schools) than American students, and research on expertise indicates that time on task is the most important factor in developing expertise.

Let me conclude by addressing the part of the question dealing with whether or not inquiry-based teaching has led to a significant increase in test scores for American students. I do not know of any large-scale systematic study of this question, important as it is. However, there are very encouraging indications that inquiry-based teaching methods are superior to traditional methods, especially for underserved students. Dr. Michael Klentschy, the superintendent of El Centro School District in the southeastern tip of California, mandated that elementary school teachers in his district use inquiry methods to teach math and science. Most teachers adopted NSF-funded curricula since those are the best examples curricula designed for inquiry-based teaching. Despite the fact that the student population is over 85% minority (mostly poor, Limited-English Proficient Hispanic children of migrant workers), test scores on the Stanford Achievement Test improved dramatically 2–4 years after these instructional methods were adopted.

A–4. In your testimony, you indicated that the workshop structure commonly used for the continuing education of in-service teachers is not aligned with findings from the science of learning. Could you elaborate on this statement by explaining more fully the disconnect between trends in teacher continuing professional development and the science of learning and by describing a more effective structure for future teacher continuing education programs?

There are several reasons why I think current practices for the continuing education of in-service teachers are not aligned with findings from the science or learning. The typical in-service experience for an in-service science teacher consists of attending a 1 or 2 week summer program with a few (typically from 2–4) follow-up days during the school year. Research on learning suggests that it takes considerable time to gain expertise in any subject, and acquiring expertise to teach in ways that reflect how people learn is no exception. Thus, teacher enhancement programs as described above may be good for *exposing* teachers to teaching practices based on learning research, but they are not sustained or prolonged enough to make a lasting impact on their classroom practices. We should be exploring and evaluating teacher enhancement models that are more sustained (i.e., lifelong), that do not require teachers to add more to an already packed schedule (i.e., that allows teachers time for reflection, instructional design and experimentation with teaching styles), and that encourage "communities of practice" where teachers discuss among themselves on a daily basis their teaching and learning experiences within their classrooms so that they can share and build teaching and learning expertise. I hasten to point out that what I am suggesting is a model that is common practice in university and industrial research & development. The major obstacle that stands in the way of implementing such a model with K–12 classroom teachers is economics—it is expensive to provide all teachers with enough release time to engage in these activities.

B—Post-Hearing Questions Submitted by Ranking Minority Member Eddie Bernice Johnson

B–1. By what means can strong ties be developed among those who perform basic research in cognition and human learning, those who perform education research, and teachers, school administrators and developers of educational materials? Does the Interagency Education Research Initiative show promise as a mechanism to achieve this kind of collaboration?

A major obstacle in forging strong ties among researchers, teachers, and school administrators is that it is somewhat difficult for university researchers, given their time constraints and "core" duties, to spend much time physically at schools working with teachers. Technology can help in this regard by forging partnerships that allow researchers to observe and interact with schools and teachers remotely, for example, by being able to observe classroom practices via the web while sitting in their offices. We currently have the technology to accomplish this, and I hope that more IERI projects explore this method of collaboration.

I believe that the Interagency Education Research Initiative (IERI) is moving toward some important objectives. The Initiative was designed to move research from small scale laboratory studies to "scaled-up" proportions. This is very difficult to do for a number of reasons, including that scaling-up means taking the innovations to classrooms of all sizes and types, to teachers of all levels of preparation, and to districts with an array of resources and commitments to innovation. We need to face the reality that accepted practice is a very powerful motivator and a very powerful force to overcome. So, I believe that initiatives such as IERI are very important for understanding what it takes to place research into school systems. I don't believe that such objectives can be achieved without a full scientific knowledge base about learners, which is to say that behavioral science, including human cognition and human learning, provide an important research base for implementation of learning science. For this reason, I believe that it is important to include fundamental behavioral research as part of any funding for large initiatives.

B–2. What are the key factors in moving research results in human learning into educational practice in the classroom?

A key factor in moving research results in human learning into educational practice is "gestation time." It is unreasonable to expect that research discoveries about human learning made today will be applicable in classroom settings tomorrow, or even next year. To make an analogy, we should keep in mind that it took decades after the discovery of lasers to put them to use in medical applications, space exploration, audio-visual technology, etc. Much of the instructional innovations taking place today apply learning research findings from 10–20 years ago. For example, many of the intelligent tutoring systems that help students achieve proficiency in math quickly and efficiently employ findings from research on expertise conducted during the 1980's and 1990's. So, I would say the key factor in moving research results on human learning into educational practice is to continue funding basic research on human learning and allow for the proper gestation period.

B–3. The NSF budget proposal for FY 2002 includes a request for $200 million to fund partnerships between institutions of higher education and K–12 schools to improve science and math education through bringing research-based approaches into the classroom to improve student achievement; strengthening math and science standards and curricula; eliminating the performance gap between majority and minority and disadvantaged students; improving math and science training for teachers; and reaching under-served schools and students in creative new ways. What portion of the resources available for this initiative should be used for basic education research, and what ought to be the priorities of the research components?

I feel uncomfortable putting a number on what portion of NSF's K–12 resources should go to basic education research. However, we should look at the private sector for some clues. There, it is commonplace to find 15%–30% of expenditures going to research that could ultimately improve products or develop new product lines. Certainly 15% of the $200 million is not unreasonable given the payoff potential of basic education research in the long term (see my answer to B–3 above). Perhaps more important is that every project funded contain a research component, whether that component consists of applied or basic research is not crucial, but what is crucial is that we evaluate any program that attempts to improve on the science/math education infrastructure (e.g., evaluating the effectiveness of curricula, of teacher enhancement models, etc.). In terms of the priorities of the research component of this funding request, I would repeat what I stated in my testimony, namely that we should be finding ways to fund the best people to do the best research, and to make sure we do not exclude the talents of many excellent investigators simply because they did not join some large consortium competing for the funds.

B–4. Describe key features of a federal program to disseminate information about successful educational practices and materials and to support their widespread use?

This is a very good question since it is often the case that many successful practices or innovative curricula resulting from federal funding are "well-kept secrets" for circumstantial reasons. Let me give one example: Since most textbooks publishers publish "clones" of the archetypal traditional textbook, it is difficult for innovative curricula to find large publishing houses willing to publish, and aggressively market, avant-garde products. The smaller publishing houses that take on NSF-funded curricula are not large enough to disseminate widely the successes of the NSF-funded curricula, nor are they large enough to compete with the behemoth publishing houses.

One route to take is to establish and advertise a national web-based clearing house of educational practices, curriculum, and innovation. This site could serve as a reference service not unlike the reference services provided by libraries. First, it could provide information, but also it could answer queries from teachers and administrators about existing curricula or programs targeted to their specific needs.

ANSWERS TO POST-HEARING QUESTIONS

Answers to post-hearing questions submitted to Dr. Nancy Songer, Professor of Education, University of Michigan. Questions or comments can be directed to: songer@umich.edu

Post-Hearing Questions Submitted by Chairman Nick Smith

1. *When a new theory of education practice is developed, how much research is typically done to demonstrate that the theory is "correct" versus rigorously comparing the new theory to others? How can we build research centers and communities that conduct non-biased research on teaching and learning in spite of pressure to embrace a particularly theory or practice?*

While it would be wonderful if educational theory could be tested through experimental design in classrooms, unfortunately this is not possible. Therefore to answer your question directly—virtually none, however this does not mean that educational theories are not supported with strong research evidence. As in many other disciplines, theories are the idealized, foundational backbone behind practice and implementation. A given theory can be applied in many different contexts, often realizing differential outcomes.

Nevertheless, an implication of your second question is that we need stronger research-based centers that can serve as clearinghouses for both high quality educational research and dissemination of research results exemplified in practice. In my response to question 4 of Ranking Minority Member Eddie Bernice Johnson below, I suggest the development of sets of working exemplars of successful implementation of a given curricula or reform program that are available for critique, review, and discussion among teachers, policy-makers, and researchers. These would be affiliated with Research Partnership Centers, and serve as the currency for articulating what is working, or not working, in actual classroom settings. Aspects of this model are an integral part of the professional development of Japan, and serve as essential lifelong learning mechanisms to improve classroom practices and the impact of learning research on Japanese classrooms nationwide.

2. *Approximately what percentage of existing curricula and textbooks have undergone the kind of rigorous assessment required to evaluate their impact on student learning and to determine how best to use these resources for optimal classroom instruction? What models exist for rigorous assessment of curricula and textbooks for their impact on student learning?*

My response to this question resembles my response to Question #1 above: Curricula and textbooks are not instruments that can be measured in the manner described. What can be measured is learning. As learning is a complex process, it that takes into account the influence of many factors including: the nature of resources utilized (like textbooks), the nature of the teaching practices, the social environment, and the learners' knowledge and beliefs, among other factors.

On balance, educational researchers are conducting, and need to continue to conduct, longitudinal, rigorous research to determine the range of conditions that lead to "successful" outcomes with particular curricula, textbooks, Internet resources, or any other learning resource. My belief is that programs such as the Interagency Education Research Initiative (IERI) outline important guidelines, partnerships, and models of dissemination that can help us realize these results in a timely and effective manner.

3. *Parents can be very suspicious of education research and the introduction of new instructional methods, in part because of the heated debate over phonics versus whole language methods of reading instruction. How can parents be better engaged in the education research effort?*

Educational researchers need to organize and create Research Centers, as described in these responses and in my testimony, as an important mechanisms for the nationwide organization of systematic research studies, and the organization of resources for widespread dissemination. We need these Centers to advance our understandings and, perhaps more importantly for this question, to advance our ability to communicate essential kernels of our research to the public. More details on these Centers and dissemination models are available in responses 1 and 4 to Congresswoman Johnson's questions below.

4. *While higher order thinking skills are very important as students transition from school to work so is the ability to memorize, assimilate, and recall factual knowledge. Are contemporary pedagogical practices that stress discovery over content*

mastery shortchanging students who will need memorization and recall skills when they enter the workplace?

This is a very important question, as it represents the problems experienced by both the public and educational researchers with the oversimplification and miscommunication of educational research, such as that experienced in the whole language versus phonics wars in early reading. As I believe educational researchers and the public now recognize, the best reading program is one that promotes essential characteristics of both whole language and phonics. Similarly, while current definitions of scientific literacy discuss the promotion of higher-order thinking skills, they promote this approach *in contrast* to the nearly exclusive emphasis in the past on memorization and recall, not *towards the exclusion* of instruction promoting memorization and the recall of factual knowledge. In my view, the best school-to-work programs and the best school programs in general recognize this underlying assumption. What we have not done a good job of is emphasizing that the strongest contemporary pedagogical practices that discuss a current foci on inquiry thinking in science recognize the value both in the understanding of scientific facts and concepts, as well as fluency with scientific thinking skills.

Post-Hearing Questions Submitted by Ranking Minority Member Eddie Bernice Johnson

1. *By what means can strong ties be developed among those who perform basic research in cognition and human learning, those who perform education research, and teachers, school administrators and developers of educational materials? Does the Interagency Education Research Initiative IERI show promise as a mechanism to achieve this kind of collaboration?*

As discussed by a group of national educational leaders sponsored by the American Psychological Association as they were focusing on H.R. 1 and S. 1 in June 2001, Mathematics and Science Partnerships should have the following characteristics:

a. Each partnership should include three strong partners: 1. Learning researchers. 2. Disciplinary experts (i.e., scientists, mathematicians). 3. Leader educators.
b. Each of these groups should study their own progress and evaluate their contributions using sound research methods.
c. The overall partnership program must include a strong research component that will advance our knowledge of the processes of learning, teaching, assessment, and educational change. IERI models this research-centered focus.
d. A substantial percentage of funds (we suggest 20%) should be made available for the research component and should be allocated through a national peer review process. Again, IERI models this process.
e. Partnerships need funding for the foundational years (i.e., 5 years), but should not expect sustained funding. Mechanisms should be investigated for ownership and sustainability beyond this initial funding period.

In many dimensions, IERI shows great promise as one mechanism to achieve this kind of collaboration. For example, IERI places a strong emphasis on both quality research and tangible outcomes and impact in large numbers of schools. The tangible, widespread impact we desire can only be achieved through the kinds of large research infrastructure and multi-disciplinary partners required in an IERI grant. In addition, the tangible, widespread impact we desire can also only be achieved through focus on particular reforms for more extended periods of time, as IERI demands. This longevity allows reforms and partnership relationships enough time and continuity so that reforms can get to the point that tangible and meaningful research outcomes are clear and easily communicated.

2. *What are the key factors in moving research results in human learning into educational practice in the classroom?*

Improving classroom-based practice requires using and extending what we know about effective learning, teaching and learning environments. Capstone documents exist that summarize what we know (see for example the National Research Council report, *How People Learn*).

Key factors in moving research results on learning into educational practice include:

a. Specific Partnership Centers as clearinghouses for the generation, translation into communicable forms, and dissemination of research results (see response to question 4 below for recommendations for these partnerships),

b. Congruence between testing, pedagogy and curricula, and
c. Longevity of working relationships reforms and research.

Congruence between testing, pedagogy and curricula is essential in our current focus on accountability in schools. As determined among some of the nation's leading educational researchers recently (sponsored by the American Psychological Association), assessment is a valuable tool if done properly, however methods of assessment now being used in most education accountability systems rely on a 75-year-old technology. Major advances have been made in assessment techniques that should be fully integrated into the educational process (see the National Research Council report, *Knowing What Students Know*).

Finally, schools have seen far too many reform-fads come and go. Large-scale impact requires long-term commitments from school administrators, educational researchers, funding agencies, and teachers. IERI provides 5-year funding cycles, and demands cooperative, sustaining partnerships. Without a minimum of five years funding, our current work could not, for example, build and support the necessary infrastructure in Detroit Public Schools that might allow sustained reforms and the multi-year research studies that can measure sustained impact. In addition, our research demonstrates that most educational reforms do not realize large-scale impact until approximately the third year of implementation. Teachers, students, and researchers need longevity to effectively demonstrate sustainability and impact on learning.

3. *The NSF budget proposal for FY 2002 includes a request for $200 million to fund partnerships between institutions of higher education and K–12 schools to improve science and math education through bringing research-based approaches into the classroom to improve student achievement; strengthening math and science standards and curricula; eliminating the performance gap between majority and minority and disadvantaged students; improving math and science training for teachers; and reaching undeserved schools and students in creative new ways. What portion of the resources available for this initiative should be used for basic education research, and what ought to be the priorities of the research component?*

As mentioned in response 1–d, I recommend a minimum of 20% of total funding to go specifically towards research efforts. Research priorities should include studies that specifically focus on how people learn math, science, reading; what the best teaching practices are; how new technologies can be harnessed towards learning goals; and what school organizations support powerful learning. In particular, I recommend a priority on:

a. Longitudinal studies of student learning measuring long-term impact of reform programs on learning outcomes, attitudes, and beliefs.
b. Longitudinal studies of teacher learning and practices, again measuring long-term impact of reform programs on practices, beliefs, and outcomes.

4. *Describe the key features of a federal program to disseminate information about successful educational practices and materials and to support their widespread use?*

Dissemination of key information about successful educational practices has proven to be challenging for many reasons, including a somewhat widely held misconception that educational programs work somewhat like medicine—i.e., they are given to specifically address a particular problem towards a largely reproducible outcome. Unfortunately, my research suggests that the same reform program implemented in 250 classrooms yields 250 differential learning outcomes, even if many contain some of the same general features. In other words, while most of the 14,000 students working with the same 8-week weather program will learn foundational ideas about weather concepts, the specifics of what they learn and how varies tremendously.

As a result, I believe we need models of dissemination that *display a set of working exemplars of success with a given curriculum* or *reform program*. These working exemplars could be affiliated with the Research Partnerships mentioned earlier. Other countries, such as Japan, provide centralized systems for life-long teacher professional development that provide observation and discussion of several working exemplars of practice that are consistent with current research findings. We need, at a minimum, a digital library of video clips, lesson plan examples, facilitated Internet discussions and other resources *targeted around particular curricula or reform programs* to begin to articulate and exemplify various successful models of research-in-practice and exemplary application of research results. A stronger version of this idea involves the systematic development of online courses offered through Centers for in-service, pre-service teachers' ongoing discussions of pedagogical practices current with educational research.

ANSWERS TO POST-HEARING QUESTIONS

Answers to post-hearing questions submitted to Dr. Chris Dede, Chair, Learning and Teaching, Graduate School of Education, Harvard University, 323 Longfellow Hall, 13 Appian Way, Cambridge, MA 02138; (617) 495-3839

Post-Hearing Questions Submitted by Chairman Nick Smith

1. When a new theory of education practice is developed, how much research is typically done to demonstrate that the theory is "correct" versus rigorously comparing the new theory to others? How can we build research centers and communities that conduct non-biased research on teaching and learning in spite of pressure to embrace a particular theory or practice?

An analogy to diets can help to clarify the issues involved in proving that a particular education practice is better than alternative approaches. A great deal is known about nutrition, health, and exercise from a basic research perspective; and scientists have established that any successful, sustained loss of weight must involve permanent changes that include eating less and exercising more. However, there is enormous disagreement about alternative approaches to dieting, conflicts that scientists and nutritionists are largely unable to resolve by providing hard evidence. The reasons for this are that the success of a diet in any given individual depends on:

- the particular physiology of that individual, and
- the extent to which that person accurately follows the prescribed activities involved in the diet and its aftermath.

For example, diets such as eating low carbohydrates and high fats—or vice versa—vary in their impact from one person to another depending on idiosyncratic physiological issues and also on the ability of the person to honestly follow the diet and to provide accurate self-reports about what he or she ate and did. As a result of this situation, a plethora of diets exist, each with contradictory claims, and large-scale studies have not established some set of "best" diets that the American public will accept and follow. The wishful thinking intrinsic to human nature coupled with pervasive misinformation put forward by vendors with economic interests in particular types of food products further complicate this issue. The best approach seems to be what public health officials are doing: stressing the overall benefits of balanced nutrition and reasonable exercise without attempting to rank-order a particular set of dieting strategies.

Establishing a widely accepted set of "best" diets is simple compared to accomplishing the same task for educational practices. The correct implementation of an educational practice involves many more variables than the proper implementation of a dietary regimen (e.g., preparation of the teacher, match to student learning styles, willingness of the school culture to provide the conditions necessary for success). In comparison to nutrition and exercise, individual variability in learning styles is higher, misinformation and naïve cultural attitudes about education are more pervasive and entrenched, and determining what shifts constitute "success" (e.g., learner motivation, self-image, content acquisition, skill mastery, higher order thinking) is more complicated than simply measuring loss of weight. Therefore, conducting large-scale controlled comparison studies of education practices is very complex and expensive.

[The problems with these comparative studies are typically not due to bias within the research community. Published articles in research journals and presentations at research conferences are held to high methodological standards. Of course, numerous unsubstantiated claims are made in magazines and promotional materials for practitioners, but this is true in many fields.]

Moreover, even if results from large-scale controlled comparison studies of education practices were widely available, their usefulness would be limited. First, people at every level (from parents to members of Congress) seldom make decisions about education on a rational basis. For example, a substantial research literature has established findings about class size that few states or districts implement, because they would involve economic and political choices that the public, education administrators, and politicians don't want to make. The 1999 National Academy of Sciences report, *How People Learn,* written for members of the public and policymakers, has had almost no impact on educational decision-making despite the fact that it documents many proven research results about education practice.

Second, even when people choose to be rational, some types of scholarly findings about education practices decline over time in their utility. For example, what is appropriate and intriguing as content for middle school students today may not be in a decade, due to changes in the family and society, in contrast to fundamental aspects of nutrition and exercise that change much more slowly. At a time of rapid change in society, best practices in education alter less rapidly than those in business or politics, but still change quickly enough to make the "half life" of many studies of practice shorter than anyone would like.

None of this is meant to argue against the value of conducting comparative research on education practices. The point is to recognize the high cost and limited utility of large-scale investments in improving education through such a means. Overall, the best approach is analogous to that in public health: promote good overall approaches to learning (based on the research presented in resources such as *How People Learn*) without attempting to rank-order the value of specific education interventions. How to prepare people to make intelligent choices about the specific individual and organizational educational situations that they confront is discussed further in my responses to the questions that follow.

2. *Approximately what percentage of existing curricula and textbooks have undergone the kind of rigorous assessment required to evaluate their impact on student learning and to determine how best to use these resources for optimal classroom instruction? What models exist for rigorous assessment of curricula and textbooks for their impact on student learning?*

The answer to this question is related to my response for question one, Very few curricula and textbooks are rigorously evaluated, because such evaluations are complex, expensive, and have limited generalizability. Moreover, those evaluations that have been done are often subjected to political oversight that undercuts their objectivity and effectiveness. One example is the Congressionally mandated Expert Panels for the U.S. Department of Education. When the Math Education evaluation results were announced, some members of Congress held hearings attacking the work of the Math and Science Education Expert Panel because political interest groups objected to the results of the evaluations (without technical merit to their opposition). As a result, the other Expert Panels were dismantled and their findings not published.

This response is not an argument that evaluations of curricula and textbooks should not be done, at least for those produced with federal funds. The National Science Foundation has set a high standard of excellence in its evaluations of recently funded curricula, such as GenScope; U.S. Department of Education projects should be held to a similar level of excellence. The point is that the outcomes of these studies are typically ignored or attacked, rather than followed, whenever the results of this research conflict with the interests of political groups or the misconceptions of the public. This makes the investment of large amounts of federal funds in comparative studies a mechanism of limited leverage in education reform, especially given the issues of generalizability discussed earlier.

3. *According to the National Center for Education Statistics,* 99% of public school teachers have computers available to them in their schools, and 84% have at least one computer in their classroom. However, less than 10% have more than five computers in the classroom. Given these statistics, are we ready to use technology in classroom instruction, and do we know how best to use technology for direct instruction, supplemental instruction, teacher professional development, and student assessment?

The bulk of my written testimony deals directly with this question and establishes that much is known about the effective use of technology in school settings. This includes classrooms with a single computer, or with all the school computers in laboratories and none in classrooms, although these are not optimal arrangements. At this point, the primary issue in technology usage is not purchasing additional equipment, but transforming content and pedagogy to more effective practices using technology as part of the interventions required to accomplish this.

Again, a major barrier is the refusal by the public, educators, and politicians to make rational usage of the research results available, rather than a dearth or lack of quality in studies of effective technology usage. For example, this year the National Academy of Sciences published a report, *Knowing What Students Know*, documenting numerous effective uses of technology in student assessment, supported by a wide array of basic research findings. However, both political parties and the American public continue to support a simplistic, naïve "test and punish" strategy for education reform (as described in my oral testimony) that ignores these results about technology usage in student assessment.

This is not to say that research on effective uses of technology in education is not a useful and important investment; my written testimony argues strongly for further funding of this type. The point is that, when the research community gains insights about an educational issue and publishes its results, much remains to be accomplished in educating the public, educators, and politicians before educational administrators are willing and able to act on those insights. My testimony and my responses to the questions below speak to the types of additional dissemination, adaptation, and capacity building needed.

4. *Given the rapid evolution of hardware and software, already strained school budgets, and the apparent lack of knowledge about how best to use technology in education, is the national investment in instructional technology for schools premature?*

There is not a fundamental lack of knowledge about how best to use technology in education. On the contrary, many more studies exist establishing the effectiveness of technology and ways to use it well in classrooms than there are studies documenting the value of the interventions (e.g., block grants, massive federal testing) in the recent, highly questionable "education reform" legislation massively endorsed by the Congress and President and widely accepted by the public. The evolution of technology is a further argument in favor of its deployment, since American business has realized productivity gains as the power of computers and telecommunications increase while prices drop. Strained school budgets are also a reason for supporting the implementation of educational technology; again, business has found that transformative usage of computers and telecommunications (as opposed to automating traditional work practices) is a means of saving money.

The primary issue, as described in my oral testimony, is that educational technology is often not used well—and the conditions for its success are very difficult to realize—in the current climate of education "reform." Only when more rational, research-based strategies for the improvement of education is adopted by the public, educators, and politicians will the potential power of national investments in learning technologies be fully realized.

Post-Hearing Questions Submitted by Ranking Minority Member Eddie Bernice Johnson

1. *By what means can strong ties be developed among those who perform basic research in cognition and human learning, those who perform education research, and teachers, school administrators, and developers of educational materials? Does the Interagency Education Research Initiative show promise as a mechanism to achieve this type of collaboration?*

Dr. Nora Sabelli and I have recently completed a paper that addresses this issue (cited in my written testimony). Here are excerpts that speak to mechanisms for linking research and practice:

"The strategy we advocate for increasing the impact of research on education practice goes beyond "transfer" and "action research" towards reconceptualizing the relationship between scholarship *and* practice as instead a scholarship *of* practice. An analogy for understanding a "scholarship of practice" is to consider the levels of experimentation and applied research that take place *after* scientific research in the physical sciences is conducted and published, and *before* the results of this research are applied large-scale in society. The field of education does not provide roles akin to engineering for developing research prototypes into robust practices and products. As discussed later, the outcomes of research include people, not only knowledge, and transfer between research and practice is implemented through both scholarly products and human capacity-building.

For example, the National Institutes of Health (NIH) strategy of incorporating use-driven research perspectives into the definition of clinical research and research trials has much to offer our distributed and fragmented education system, including potentially shortening the time frame in which education research can have real and sustained impact in schools. NIH has recently revised its policies for funding medical and public health research on the basis of its past successes in medical research, coupled with failures in using similar strategies in advancing the public health aspects of medicine.[1] These changes highlight the parallels between education and the public health aspects of medical research, rather than medical research per se. In developing better methods of applying research in schooling, education scholars should consider how and why existing models for implementing research in practice outside of education succeed (or fail).

Beyond reformulating models of research application, the under-funding of educational research compared to other fields' investments in scholarship results in a

[1] The Office of Behavioral and Social Sciences Research was created in the Office of the Director, NIH, in 1995. See http://obssr.od.nih.gov/about.html. See also *Bridging Science and Service, A Report by the National Advisory Mental Health Council's Clinical Treatment and Services Research Workgroup*, NIMH, *http://www.nimh.nih.gov/research/bridge.htm*

dearth of research-minded practitioners who join the instructional workforce in its many guises. This in turn undercuts a generative, field-driven demand for quality research that speaks to practice. Allocating a greater proportion of education expenditures to research, as well as increasing the research preparation of practitioners, would contribute to solving many problems of capacity in education that have been discussed lately, including the need for a higher quality instructional workforce and for instructional leadership in the school's administrative hierarchy.

What is required from research-minded practitioners is not "action research" along the lines of academic research carried out in classrooms. Rather, it is the more profound experimental ethos of (and support for) data-driven iterative assessment and revision of classroom practice by practitioners with the collaboration of researchers. Practice-minded researchers need concomitant recognition of the new ways in which the expertise of researchers and practitioners interact. The practice of education is always localized to the interactions of a particular student or group of students, with a particular instructor, and within a particular environmental context. Any general conclusions and recommendations of research need to be adapted to specific local conditions and capacity, before they can be expected to show results.

Principled localization of general research knowledge requires more than manuals, textbooks, and a vision of what "good practice" ought to be. Localization requires the ongoing hard work of thinking through options and evaluating them, based on very specific sets of conditions and resources, to arrive at a *path* for action. Excellence is not achieved in one jump; reflective modification of this path is the "experimentation" that leads to optimizing gains. Partnerships such as those advocated by the LETUS group[2] and by Confrey et al.[3] are centered on the content and pedagogy of specific instructional activities and have stringent requirements for the preparation of researchers and practitioners. Graduates of these learning partnerships are able to experiment on demand within specific classroom situations, simultaneously gaining understanding from such experiments and revising them to obtain increased student learning.

The Interagency Education Research Initiative (IERI) is an effective program based on the belief that too little emphasis has been placed on funding for *in-situ* adapting, analyzing, and scaling-up interventions and policies that, as isolated islands of innovation, have been successful in some educational contexts. *[To disclose a possible source of bias here, I am a co-investigator on an IERI grant.]* We believe that even less priority has been given to modeling and generalizing the coherent processes that led these innovations to succeed in design experiment settings and other implementation venues. To achieve sustainable and optimal change, we posit that understanding the process of innovation by teachers and administrators (i.e., how they alter their standard practices) is as important as studying the outcomes and the instructional practices that we wish others to replicate.

Such knowledge cannot be obtained using a dissemination strategy. Dissemination implies that the changes that take place in new sites will be minor or non-existent. We know that that is seldom the case, and that critical aspects of innovations are most often co-opted when performed in isolation from their bases on research. In essence, we are saying that innovations studied by researchers succeed because of the special flexibility provided by the presence of researchers. We need to develop strategies for reproducing not only the innovation itself, but also the environment that led to its success. Additional federal funding is needed for programs such as IERI, but also for research initiatives beyond this that are based on a scholarship *of* practice and speak to the issues above.

2. *What are the key factors in moving results in human learning into educational practice in the classroom?*

Here is additional material from the Sabelli & Dede paper that speaks directly to this issue:

"Education research problems and methodologies in human learning span many disciplines, whose goals and methods need co-adaptation to effectively address the complex components of educational practice. This adaptation calls for the nurturing of communities of researchers that share language, methodologies, and goals across disciplinary boundaries—the only way to avoid "a bridge too far."[4] Two examples will suffice to highlight the possible gains to practice of research that purposely integrates this breadth of topics. One is the work of Huttonlocher, Gentner,

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[2] *http;//www.letus.org/aboutus.htm*

[3] *http://www.edb.utexas.edu/syrcc*

[4] *Education and the brain: A bridge too far.* Bruer, J.T. (1997, November). Educational Researcher, 4–16.

Newcombe et al. on understanding and fostering spatial competence.[5] Another is implicit in the work of Dehaene[6] on the neural mechanisms that underlie counting and estimating, and the related work of Gelman and collaborators[7] on the interaction between the structure of the brain's learning mechanisms and the structure of the data that support learning.

Figure 1 is one view of the different aspects (quadrants) in NSF's formulation of education research and includes a placeholder for the "system changes" research to be discussed later. The use of the word "network" in this context deserves an explanation. We want to avoid any implication of a linear continuum between research and practice, or of a continuum of granularity levels from individual to social. Every quadrant has its own set of granularities, from small to large, and every quadrant may include aspects of practice. There is a qualitative change of focus in bridging quadrants. This change redefines the conceptual scales, and it is this redefinition that encourages posing questions from different perspectives. Redefined questions demand a rethinking of the methodologies used to answer them, and offer the possibility of new insights. Thus, the *network of quadrants* should reflect the limits of a reductionist approach to studying the complex nature of education.

The quadrant labeled "Components of contextualized practice" provides *use-driven* problems for research to consider, stemming from issues in curriculum, pedagogy, assessment, professional development, etc., that relate to fundamental issues of human learning. Other quadrants represent various types of research that contribute in different ways to understanding and improving practice. These include studies of individual learning at biological scales, of social learning by individuals and groups, of the organization of the educational system, and of policy and economic issues. These areas of research run the gamut from immediate usefulness in practice to setting the stage for advances a decade hence, and from individual phenomena to organizational dynamics—i.e., along axes of both time and aggregation.

Each quadrant receives outside inputs (methodological, problematic) from less *education-problem driven* aspects of contributing disciplines. Besides framing disciplinary aspects of research in terms of their contributions to practice, such a conceptual framework highlights the importance of the *interfaces between quadrants* as areas where research is needed and where the nurturing of cross-disciplinary communities of scholarship is of paramount importance.

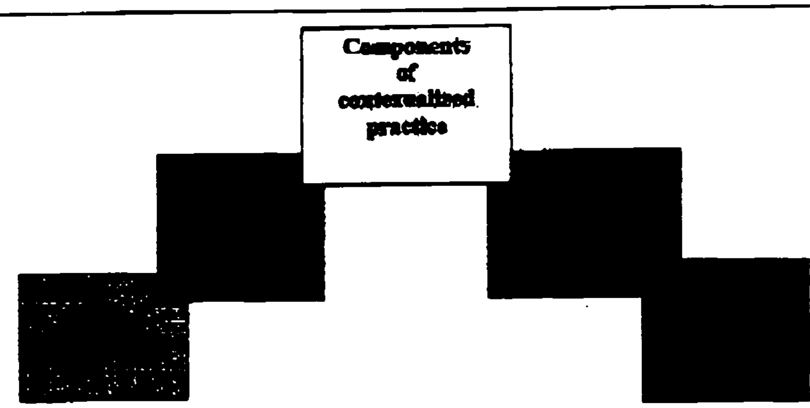

Figure 1. ***Reification of the concept of a continuum of use-driven education research.***

Quadrant 4 in Fig. 1 is the home within NSF's portfolio for studies that explore educational systemic issues. The relationship between this quadrant, the IERI program, and the types of research we advocate for is shown in Fig. 3 where the

[5] *Understanding and Teaching Spatial Competence.* J. Huttenlocher, D. Gentner, N. Newcombe *https://www.fastlane.nsf.gov/servlet/showaward?award-0087516* (and prior awards)

[6] *The Number Sense: How the Mind Creates Mathematics.* Stanislas Dehaene; Oxford Univ Press 1997.

[7] *Learning in Complex Environments by Natural and Artificial Systems.* R. Gelman, C. Taylor, E. Stabler, O. Chapman, C. Gallistel. *https://www.fastlane.nsf.gov/servlet/showaward?award-9720410. The Children Understanding of Number.* R. Gelman and C. Gallistel, Harvard University Press, 1978.

placeholdcr for "system changes" shown in Fig. 2 is analyzed. The IERI program represents an extension of implementation research into the conditions for scalability and sustainability. "Sustainable localized system changes" represents the type of scholarship of practice that we advocate.

In our strategy (see Fig. 2), we differentiate research on separate aspects of education practice (e.g., the cognition of teaching and learning), from studies of these components embedded into a sustainable implementation in real contexts (policy and practice research on education innovation). The middle box in Fig. 2 is crucial, because this type of research bridges and connects advances in isolated portions of educational practice with an understanding of the policy and systemic actions that promote or hinder their classroom applications in a scalable and sustainable way.[8,9] Illustrative examples of research that falls into this middle box include:

- creating strategies for the sustainable, large-scale adoption of experimental learning technology prototypes into educational practice[10]
- using statistical data for assessing student progress to provide professional development on content-specific pedagogy and teacher proficiency[11]
- understanding how to foster the conditions for productive participation of novice learners in scientific research.[12]

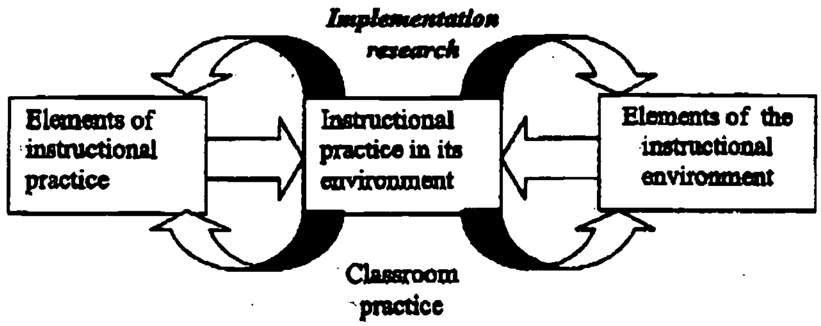

Figure 2. *Type of Research Studies on Changes in the Practice of Education*

The three bullets illustrate non-exclusive aspects of how the term "implementation research" has been used by the groups referenced. The parallel interests of implementation research are (a) to contribute to sustainable and optimal improvements in practice *in a given environment, responsive to that environment,* and (b) to treat the process as a local experiment where researchers and practitioners can support and reflect on the development *of the site* as a "learning organization." By "sustainable and optimal" we mean research that succeeds in raising the expectations and practices of the implementation site to match the maximum gains that could be achieved under given conditions. To achieve sustainability, research must help raise the local capacity for negotiating with policy-makers the time frames for achieving expectations, and then engage in continuing to raise these same expectations.

Such work must take as its bases a consideration of local conditions *at that implementation site,* the development of human and infrastructural capacity for principled improvement *at that implementation site,* and the uncovering of a path for continued organizational learning *at that implementation site.* Often, at that site this research strategy requires a combination of design experiments, the creation of ongoing support relationships among researchers and educators, and the need for ongoing re-

8 *Systemic Crossfire: What Implementation Research Reveals about Urban Reform in Mathematics.* J. Confrey, K. Bell, D. Carrejo, unpublished (AERA 2000 presentation).

9 *Systemic Educational Change: Towards A Complex Systems Perspective.* J. Lemke et al. Complexity and K–16 Education: Working Group 3 Draft Report, *http://www.necsi.org/events/cxedk16/edreform.html*

10 *The Living Curriculum Project.* L. Gomez et al. *https://www.fastlane.nsf.gov/servlet/showaward?award-9720423*

11 Work with Fathom and Student TAAS Data. *Proposal for a Systemic Research and Design Center in Mathematics, Science, and Engineering Education;* Confrey et al. *https://www.fastlane.nsf.gov/servlet/showaward?award-9816023*

12 *Center for Highly Interactive Computing in Education.* http://kidsideas.org/investigationstation

search on locally posed questions. This integrated type of system-embedded research is what we call implementation research. It requires collaborative teams of researchers and practitioners involved in co-design and co-analysis, as well as the use of experts outside of education, such as social psychologists, complex systems theorists, organizational researchers, policy analysts, and economists. In these research partnerships, providing support mechanisms for participating practitioners to learn the language, methods, and culture of research is essential.

In this situation, the implementation site experiences individual and organizational learning from its own attempts—via an ethos of experimentation. The operational term for describing the relation between research and practice is not for us "transfer" or even "integration"; rather, it is "integrated co-development."

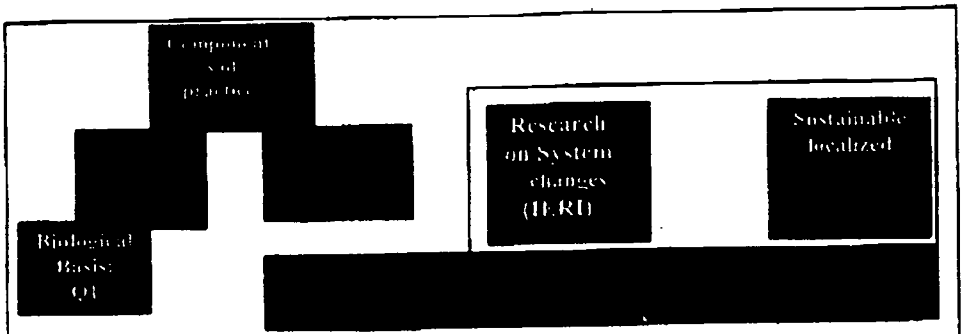

Figure 3.- Extension of the continuum research model to integrate localization research.

Funding new research programs such as we describe that stress integrated co-development is a powerful way of moving scholarly findings about human learning into educational use in classrooms.

3. *The NSF budget for FY 2002 includes a request for $200M to fund partnerships between institutions of higher education and K–12 schools to improve science and math education by bringing research-based approaches into the classroom to improve student achievement; strengthening math and science standards and curricula; eliminating the performance gap between majority and minority and disadvantaged students; improving math and science training for teachers; and reaching under-served schools and students in new and creative ways. What portion of the resources available for this initiative should be used for basic education research, and what ought to be the priorities of the research component?*

First, only "use-driven" basic research as described above should be funded as a part of this initiative. Any other types of basic research funded by this initiative, while worthwhile as scholarship, would fail to improve science and math education just as curiosity-driven or theory-driven studies have provided little leverage in other, similar attempts to alter practice.

Second, the priorities of this research component should flow from the lessons learned at NSF from the problems and difficulties of its various "systemic reform initiatives" (Statewide System Reform, Urban Systemic Reform, etc.). These projects typically had little sustained, meaningful impact on education practice despite goals and mechanisms similar to those proposed in this $200M request. Only if this new initiative is based on insights about the limited leverage of those earlier programs will it bear greater fruit.

Third, the new initiative must take into account in its use-driven basic research some fundamental issues about education practice not often considered by scientists and mathematicians at academic institutions. Below is feedback about these issues that I have already provided to NSF in the content of this initiative:

"MSPI assumes that higher, standards in math and science, as upheld by academic scientists and mathematicians, are the major missing ingredient in quality education. This assumption seems suspect in a number of ways.

- The content standards in math and in science already are overburdened with many low-level types of factual knowledge rather than fewer fundamental ideas and skills taught deeply, and inviting academic mathematicians and scientists to make the curriculum more rigorous is likely to make this problem worse rather than better, as each sub-speciality includes its material to recruit promising students. Including non-academic scientists and mathematicians, who have a better sense of what every worker and citizen needs to know, could help with this issue.

- Also, if the initiative succeeds only in its narrow goals of improving education students science and math preparation, when potential pre-service teachers have strong skills in science and math they typically will shift to a different, more technical career with a higher salary, better working conditions, and more respect from the community—unless some other, simultaneous intervention takes place that alters the status of teaching as a profession.
- In addition, schools of education are not mentioned in the initiative, consistent with the predominant view of scientists and mathematicians that these academic areas are of low-quality and part of the problem rather than a vital component of the solution. In fact, a major part of the difficulties in math and science education is the poor teaching practices of academic scientists and mathematicians, who frequently assume that there is no such thing as pedagogy and that content knowledge is all that is needed to make a successful professor. I believe that both schools of education and academic departments in science and math have much to learn from each other if this initiative is to succeed.
- Regardless of any other form of intervention, until student assessment metrics are more sophisticated than high-stakes, low-level tests, flawed accountability measures will continue to drive the curriculum (and drive down students' knowledge of higher order science and mathematics). The recent National Academy of Sciences report, *Knowing What Students Know,* outlines a research agenda promising in its opportunities to improve these types of assessments. As part of MSPI, scientists and mathematicians should be involved with improving assessments, especially because—as with pedagogy—they have a lot to learn in this area if they are to model effective assessment practices for present and future teachers.

Thus, implementing MSPI in its present form will likely worsen rather than improve the situation. More of a research perspective based on NSF's prior experience with this issue is needed. In framing MSPI, NSF should first analyze various situations around the country where scientists and mathematicians have become more involved in teacher preparation and professional development, studying what problems and issues have arisen as a result (such as NSF's own systemic reform initiative programs including SSI, USI, and LSI. I suspect you will find that these initiatives are successful only when a systemic perspective on change is considered, and all stakeholders are involved as equal partners, each remediating their own weaknesses.

The State, Urban, and Local systemic initiatives sponsored by NSF have largely failed due to poorly defining the problem faced—hopefully MSPI will not be another example of this problem. Good researchers learn from their mistakes. . .

This feedback illustrates a range of seminal problems that could profit from use-driven basic research incorporated into the proposed MSPI initiative.

4. *Describe the key features of a federal program to disseminate information about successful educational practices and to support their widespread use.*

Below are additional excerpts from the Sabelli & Dede paper that speak to the issue of new strategies for more effective dissemination/adaptation:

"As has been suggested by the President's Committee of Advisors in Science and Technology (see ref. 5), if our ultimate goal is long-term, pervasive, quality educational improvement, we must find ways to invest a "critical mass" of funds and human resources in *clinical-type research.* This paper argues for a definition of such research as reflective interplay between basic research and practice, a process that is bi-directional and helps both sides evolve towards increasingly sophisticated objectives along the lines of recent redefinitions of the compact between research and the public."

In such a relationship, innovation is not followed by dissemination: the expected acceptance of recipes and materials for innovation developed by others. Innovation is instead the reflective adaptation or recreation of a process that enabled a similar group to succeed in another educational setting. Scholarship needs to provide validated examples of processes carried out under similar circumstances. Local innovation will then take these processes and chart a path from their own current capacity to a similar but evolving goal. Focusing on the process as well as on outcomes enables practitioners to start with objectives consistent with their own current problems and worldview, then evolve towards increasingly more powerful goals as they reflectively adapt innovations and engage with scholars in answering research questions needed for principled adaptation.

Table 1.- Different Styles of Classroom Research on Innovation and Practice.

Term	Definition	Characteristics	Question
Innovation	A new curriculum, technology, material, etc. and associated pedagogy	May include isolated classroom studies	Is this an useful pedagogy?
Intervention	The use of that innovation in one or more regular classrooms	My include outside evaluation	Is this pedagogy apt to be disseminated?
Intervention Study	Interventions are always experiments, but not always treated as such	Includes extensive evaluations	Does the pedagogy work?
Implementation Research	The study of mutual impacts of the innovation and the intervention	Ongoing work by the site and by the research team	How can the site learn about the nature of pedagogy from the study?
Clinical Research	The aggregation of outcomes from multiple intervention research studies	Requires a common framework	What is the range of applicability of the pedagogy?

Table 1 differentiates between types of classroom studies and the research questions that we believe should drive them, and is an attempt to place implementation research in an ecology of studies that bridge traditional research and practice. Certainly, this type of research on the sustainability and scaling-up of reforms is expensive, people-intensive, and time consuming; but these are not the only reasons why such studies are seldom done'.[13] Implementation (systemic, applied) research does not fit well within conventional scholarly academic career paths. These studies demand a multiplicity of expertise and of theoretical and methodological perspectives; this type of scholarship also requires researchers to share control of the investigative process with practitioners and policymakers. When such close partnerships are in place, researchers must not only relinquish sole power over the analytic process, but also act as brokers to guide and mediate the reflective interactions of other stakeholders. This is a skill for which most investigators are not prepared—in part because conceptual frameworks for this type of research are not well developed, in part because this capability is best fostered through supporting changes in practice within integrated implementation and research "testbeds" (an uncommon experience for scholars), and in part because such goals and flexibility are seldom allowed by funding agencies.

In our view of research, the conventional intent of large-scale research endeavors to achieve an expected outcome instead shifts to sustained planning for continual, reflective evolution. In our view, even the best of predetermined goals too often leads to implementations that call for either locally unattainable or unimportant outcomes, or worse, to the co-opting of the original goals to make them locally viable. Evolving objectives, on the other hand, require developing a shared, long-term vision of what excellence in education means.

For example, one of the authors is a co-investigator in a five year IERI project studying how the systematic usage of scientific models in the high school curriculum shapes students' cumulative motivation and understanding in science, as well as learners' generic understanding of models. The co-design and co-analysis by participating practitioners of our educational interventions is essential for enabling the large-scale integration of alternative curriculum. This involvement can lead to a sus-

[13] See footnotes 21–25.

tained process of innovation in science education that persists after our specific curricular studies are finished.

Some central questions in a process of mutually conducted implementation research are: What are the critical insights needed *here and now* to plan for and achieve an educational system's long-term goals? What is the existing knowledge base in a particular situation, and where are the pressure points in that context for augmenting that knowledge? What types of intermediaries can aid or subvert the institutionalization of an ongoing relationship between practice, policy-making, and basic, applied, and systemic research? Current research funding programs seldom take these kinds of questions into account in the criteria they use for peer-reviewed allocation of resources.

Federal funding programs such as those advocated in this paper are needed to move beyond disseminating information about successful educational practices and supporting their widespread use, since these types of strategies for education improvement have historically been unsuccessful despite many attempts. Funding programs that focus on creating a mutual culture among scholars and practitioners directed to a process of reflective innovation are the best lever for large-scale improvement.

Thank you again for soliciting my advice. I applaud the Committee for its work; if I can be of further assistance, please let me know.